Benthic Macroinvertebrate Bioassessment of San Joaquin River Tributaries: Spring and Fall 2002

Daniel Markiewicz[1], Kevin Goding[1], Victor de Vlaming[1], and Jay Rowan[2]

[1] Aquatic Toxicology Laboratory, School of Veterinary Medicine: APC, 1321 Haring Hall, University of California, Davis 95616

[2] California Regional Water Quality Control Board, 11020 Sun Center Drive #200, Rancho Cordova, CA 95670-6114

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Executive Summary

The objective of this study was to assess benthic macroinvertebrate (BMI) community structure and physical stream habitat conditions at several sites on tributaries to the San Joaquin River. Some sites were on agriculture-dominated waterways while other sites were not. Sites were sampled in spring and fall 2002. A further aim was to identify environmental factors that potentially affect BMI assemblage structure and integrity/condition. Generalizations of stressor response 'signatures' from other regions in the U.S. were employed to distinguish sites most likely to be subject to contaminant effects above the effects of channel modification and flow alteration.

A range of BMI community types occurred at sites on river tributaries, but most consisted of some to several (EPT) taxa (indicative of good habitat and water quality conditions. Sites on agriculture-dominated waterways were also characterized by a wide range of BMI community types. The sites on agriculture-dominated waterways are subject to multiple stressors and contain BMI communities comprised of multivoltine (short life cycles) insects and other organisms able to quickly re-establish populations after toxic events. This characteristic suggests that there are periodic events (e.g., flow alterations, contaminant pulses, etc.) that preclude existence of long-lived taxa in BMI communities. Sites on some agriculture-dominated waterways manifested an absence of larval insects, which may indicate severe contamination of water or sediment at those sites.

Analysis of the spring dataset revealed that BMI community structure correlated with many physical and water quality environmental variables. In the fall dataset flow, nutrients, arsenic, zinc, total organic carbon (TOC), and several physical habitat variables correlated with BMI community structure. As proposed in an earlier report (de Vlaming et al., 2004b), current results suggest that many environmental (physical and water quality) factors interact to determine BMI community composition and condition. Data collected in both studies provide convincing evidence that physical habitat quality is an important determinant of BMI diversity.

Efforts to identify BMI community that occur in the presence of particular stressors suggest that insect-poor aquatic communities reflect exposure to recurring toxicity (Yoder and Rankin, 1995). A number of the least diverse BMI communities in this study consisted of very few insect taxa and low abundances of chironomids, inferring that these sites are potentially contaminant-impacted. Multivariate analyses revealed other sites with community characteristics similar to these least diverse sites, where the risk of contamination may be lower, but still present.

At two sites sampled by both the multi-habitat protocol and the California Stream Bioassessment Protocol (CSBP), the CSBP sample manifested greater taxonomic diversity. These findings intimate that further comparison of BMI collection methods in low-gradient soft-bottomed waterways is needed and suggest that BMI data gathered by multihabitat and CSBP methods in these waterways may not be directly comparable.

Introduction

One criterion that can be used for placing a waterway on the Clean Water Act §303(d) list of impaired waterways is reduced biological diversity or abundance relative to reference sites (a group of sites that are not subject to intense anthropogenic stress and that define healthy biological condition). In agricultural areas subject to widespread anthropogenic stress, reference conditions are often difficult or impossible to establish, and as a consequence, aquatic life uses are difficult to evaluate effectively. The Central Valley of California is a prime example of this type of region. The California Department of Fish and Game (CDFG) has a project underway in the Central Valley to locate reference (or best attainable/least impacted) sites and describe the associated benthic macroinvertebrate (BMI) communities. Nonetheless, in the Central Valley and other similar areas, approaches to creating biocriteria without recourse to reference sites may be very useful (e.g., Chessman and Royal, 2004). One alternative to using reference sites in the development of biological indices is assessing the responses of communities along gradients of specific environmental variables (stressors).

Over the past 30 years, bioassessment methods have progressed from the development of community health indices to initial attempts at using biological community composition to study the effects of particular stressors (Southerland and Stribling, 1995; Brazner and Beals, 1997; Yoder and DeShon, 2003; Karr and Yoder, 2004). One successful attempt to associate community types with particular stressors can be seen in bioassessment programs in Ohio (Yoder and Rankin, 1995). Reference conditions for Ohio streams and small rivers were identified and categorized by geographic area. This allowed the development of numeric criteria for the integrity of both fish and BMI communities. Furthermore, their large database of complementary bioassessment, toxicity testing, water quality, physical habitat, and land use information (over 1200 sites) enabled identification of community type 'signatures' that tend to be associated with particular stressors.

The stressors shown to be associated with distinct characteristics of BMI communities in the Ohio studies included both urban and agricultural influences. The signatures of most relevance to the sites examined in the present study are those associated with agricultural runoff, channel modification, flow volume alteration, and complex toxicity. Yoder and Rankin (1995) defined the 'complex toxic' site category as being composed of those sites with land uses involving urban and industrial point sources where the following were detected: "serious water quality impairments involving toxics, recurrent whole effluent toxicity, fish kills, or severe sediment contamination involving toxics." Although our primarily agricultural dataset does not involve urban point sources, the 'complex toxic' category is relevant to the current study because the taxonomic composition of the benthic communities at some of the agricultural sites in the Central Valley bears a striking resemblance to the sites in the 'complex toxic' site category, as distinct from the other categories more usually associated with agricultural land uses.

In comparison to less agriculturally impacted sites, Yoder and Rankin (1995) found that agricultural runoff is associated with lowered diversity and lowered abundances of sensitive insect species, including most Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) taxa, and high abundances of chironomids (Diptera) species. However, sites exposed to complex toxicity revealed lowered diversity and abundances of all insect taxa, including a majority of chironomid taxa (Yoder and Rankin, 1995).

Differentiating between communities fitting the profiles of these different stressor categories is important when examining sites surrounded by intensive agriculture. Intensive agriculture as currently practiced in the Central Valley is associated with chronic impacts from sedimentation, altered channel flows, removal of instream habitat and riparian vegetation, as well as effects from toxic substances including pesticides. The community signatures detected in Ohio can complement knowledge gained in the Central Valley about relationships between environmental parameters and local BMI communities.

Contributions from many investigators of Central Valley BMI communities show clear correlational relationships between composition of the invertebrate community and anthropogenic stressors (see de Vlaming et al., 2004a, b and works cited therein, including Leland and Fend, 1998; Brown and May, 2000; and Griffith et al., 2003). In the analysis of bioassessment and environmental data collected during 2001 at some of the sites examined in the present study, de Vlaming et al. (2004b) noted three major environmental factors that were associated with between-site differences in BMI communities. Metals concentrations were negatively correlated with aquatic insect diversity and amphipod abundance, but positively correlated with the abundance of flatworms (Planariidae), which are generally found to be less sensitive to contaminants than insects and amphipods (Preza and Smith, 2001; Martinez-Tabche, 2002). Total organic carbon (TOC) was not correlated with metals concentrations, but like metals, TOC showed negative correlations with the diversity and abundance of insect taxa. TOC was associated with the presence of naidid oligochaetes, which, like flatworms, are more tolerant of contaminants than most insects (Preza and Smith, 2001; De Lange et al., 2004). Nitrogen concentration and biochemical oxygen demand (BOD) formed a third suite of stressors, uncorrelated with metals or TOC, but important to the community composition at the sites studied. The identification of these three separate gradients allowed both the characterization of BMI communities in the San Joaquin River watershed and the identification of possible stressor variables.

Metals, TOC, and nutrients are relatively inexpensive to measure and it is therefore relatively easy to characterize BMI community responses to these parameters. However, BMI community responses to other parameters such as water and sediment toxicity and the presence of pesticides are equally important but are more expensive and more difficult to measure. Extrapolation of bioassessment findings from other regions is both warranted and important in examining potential effects of these stressors. The possible prevalence of toxicity in the Central Valley can be seen by examining the listed causes of impairment in CWA 303(d) listed waters. In the Central Valley, out of 103 segments that are 303(d) listed, 52 list metals as stressors, 37 list pesticides, 7 list organic enrichment, and 3 list sedimentation (CVRWQCB 2003). Examining Central Valley BMI communities for signatures associated with stressors that have resulted in CWA 303(d) listings in other states can increase confidence in presumed causes of impairment.

Further, the appearance of a stressor "signature" in the BMI community of an unlisted waterway would suggest that further investigation of conditions in the waterway is warranted to determine if the waterway should be CWA 303(d) listed.

The objective of the current study was to assess BMI community structure and physical stream habitat conditions at several agriculture-dominated sites in the lower San Joaquin River watershed. A further aim was to identify environmental factors that potentially affect BMI assemblage structure and integrity. Generalizations of stressor response signatures from other regions were employed to distinguish sites most likely to be subject to effects of contamination above the effects of channel modification, flow alteration, and uncontaminated agricultural runoff.

Materials and Methods

This study focused on agriculture-dominated sites on tributaries of the lower San Joaquin River watershed (Table 1). Benthic macroinvertebrates were sampled in the spring and fall of 2002 (Spring event: 5/13/02 – 5/23/02; Fall event: 9/30/02 – 10/23/02). Habitat measurements were taken at the times of BMI sample collection. Water quality was measured monthly throughout the period of the study. Metals, nutrients, TOC and TSS data were collected multiple times per sampling event at selected sites.

Drainage Basin Inflows to the lower San Joaquin River

Based on evaluations conducted during the Inland Surface Water Plan (Chilcott, 1992) and initial TMDL evaluations, sub-watersheds have been identified in the San Joaquin River Basin (Figure 1a, b): Each sub-area is bounded by either the Sierra Nevada or Coast Range and is comprised of like land uses and drainage patterns. All natural and constructed water bodies have been identified in each sub-area as well as potential water quality concerns and major representative discharges to the Lower SJR (Chilcott, 1992). Bioassessment monitoring in these basins is designed to link into the multi-constituent monitoring being conducted by the SWAMP, and TMDL monitoring programs.

Northeast Basin

This sub-area has four major watershed areas, which drain to the Sacramento-San Joaquin Delta (Delta) downstream of Vernalis. The southern-most watershed area in this basin is the Farmington Flood control basin. This 371,861-acre area contains two major creeks, Lone Tree and Little Johns. Lone Tree and Little Johns Creeks are mainly used for agricultural supply and return flows, as well as flood control for the Farmington Flood Control Basin during extreme high water events. Water is stored in Salt Springs Valley, and Woodward Reservoirs and released as needed for irrigation and flood control. Lone Tree and Little Johns Creeks merge southeast of Stockton to form French Camp Slough. French Camp Slough then flows into the SJR just upstream of the Federal Deep Water Ship Channel at the south end of Stockton. The next watershed to the north is the Calaveras River watershed. During the irrigation season a large portion of the water from the Calaveras River below New Hogan Reservoir is diverted into Mormon Slough for agricultural use and returned as tail water to the river upstream of its confluence with the SJR Federal Deep Water Ship Channel in Stockton. The third watershed in this sub-area is the Mokelumne River Watershed. The Mokelumne, similar to other eastside rivers, contains cool, high quality, low TDS water from Camanche Reservoir. The Mokelumne receives discharges from various urban and agricultural sources before flowing into the Sacramento-San Joaquin River Delta (Delta) near New Hope Landing. The fourth major watershed in the Northeast Basin sub-area is the approximately 501,373-acre Cosumnes River Watershed. The Cosumnes is one of the few rivers in California that does not have a major in-stream impoundment although there are several small drinking water reservoirs on tributaries of the Cosumnes. The Cosumnes River is affected by several land uses including rural and urban communities, range cattle, vineyards and other agricultural activities. During the summer months, the Cosumnes is normally dry from just down stream of the Highway 16 Bridge in Rancho Murieta to its confluence with the Mokelumne River near Mokelumne City.

Sites in the northeast basin

SAC 003-Cosumnes River at Michigan Bar

The Cosumnes River at Michigan Bar is a natural cobble lined channel with a fairly wide riparian zone and its origins in the Sierra Nevada Mountains. The Cosumnes River mainly contains flow from natural runoff, snowmelt and off stream reservoirs including Jenkenson Lake. Up stream influences, include rural communities, vineyards, open range cattle grazing and mining. Local influences include possible runoff from extensive livestock grazing and historic mine tailings. Cattle can often be found grazing in or near the river at this site.

SAC 004-Cosumnes River at Hwy 16

The Cosumnes River at Hwy 16 is approximately 3 miles downstream of the Cosumnes at Michigan Bar sampling site. The stream is physically similar to the river at Michigan Bar; with the main land use difference being this site is down stream of the community of Rancho Murieta, and the Rancho Murieta golf course.

SJC 512 Mokelumne River at Van Assen County Park

The Mokelumne River at Van Assen Park is just down stream of Comanche Reservoir. Land uses surrounding the River at this point include rural housing and cattle grazing, and the Mokelumne River Fish Hatchery, which was not in operation when these samples were taken. It is hoped that this site will be able to be directly compared with the other river sites sampled in this study.

SJC 515 Bear Creek at Lower Sacramento Rd.

Bear Creek at Lower Sacramento Road receives agricultural discharges as well as urban storm water runoff from the Northern Stockton area. This area is urbanizing rapidly and this site should reflect any changes to the stream over time. The creek is a modified channel that has levees on both sides with an upper and lower bank. The creek banks are vegetated with grasses and there are some tules in the stream. Substrate in the creek consists mostly of hardpan clay and small gravel with some cobble around the bridge abutment.

SJC 514 Calaveras River @ Shelton Road

The Calaveras River at this point is a deeply incised channel with steep densely vegetated banks. Flow in the Calaveras River is controlled by releases from New Hogan Lake and up stream discharges of treated wastewater from the Jenny Lind Waste Water Treatment Plant (WWTP). The channel substrate is almost completely hardpan clay with some larger cobble and large woody debris. Surrounding land uses include almond and walnut orchards and cattle grazing.

SJC 503-Lone Tree Creek at Austin Road

Lone Tree Creek is a 20-mile long modified natural channel originating south of Woodward Reservoir. This mostly hardpan clay, ephemeral stream, carries natural runoff for the Farmington flood control basin during high flow periods and has a narrow but fairly diverse riparian zone. (Chilcott, 1992) During the irrigation season Lone Tree creek carries agricultural supply and return flows to its confluence with Little Johns Creek to form French Camp Slough. Local influences at this site are mainly agricultural including row and truck crops, and possible effects from dairy and other confined animal facilities.

SJC 504-French Camp Slough at Airport Rd.

Lone Tree and Little Johns Creeks come together just east of Hwy 99 to create French Camp Slough. French Camp Slough then flows to its confluence with the San Joaquin River southwest of Stockton. The slough is dominated by agricultural return flows and operational releases during the irrigation season and contains mostly storm water from the Farmington Flood Control basin in the winter months. Upstream land use include row and truck crops, confined animal facilities, a golf course and a landfill. Substrate in French Camp slough is dominated by hardpan clay, similar to the Calaveras River and Lone Tree Creek.

Eastside Basin

The Eastside Basin contains the three largest SJR tributaries in terms of flow, the Merced, Tuolumne, and Stanislaus Rivers. Below the major upstream reservoirs, McClure, Don Pedro, and New Melones, the Eastside Rivers have varying discharges to support withdraws from municipalities and agriculture before flowing into the SJR. All three Rivers are considered to be high quality water containing low levels of salts, Total dissolved solids (TDS) and other Trace elements. The Merced River Watershed is the southern most watershed in the Eastside basin. The lower Merced River Watershed below New Exchequer Dam covers about 180,000 acres, and contributes approximately 15 percent of the lower SJR flow. The next major watershed to the North is the Tuolumne River Watershed. The Tuolumne River Watershed below New Don Pedro Reservoir is approximately 162,000 acres and contributes approximately 27 percent of the total flow of the lower SJR. The Stanislaus is the Northern-most Watershed in the Eastside Basin. The Stanislaus River Watershed below New Melones Reservoir contributes approximately 18 percent of the total lower SJR flow at Vernalis from its 97,000 acres. Aside from the three major tributaries in the Eastside Basin, there is an area of about 305,000 acres, which is being called the East Valley Floor that drains directly to the lower SJR via a series of irrigation and drainage canals.. These canals contain water from a variety of sources including agricultural surface returns, urban runoff, treated municipal wastewater, ground water, and natural stream flows. The area draining directly to the SJR has three major sections. One large section between the Merced and Tuolumne Watersheds, one smaller area in the North between the Stanislaus and Tuolumne Watersheds, and one to the South between the Merced River Watershed and the Southeast Basin. These laterals and drainage canals contribute approximately 4 percent of the lower SJR total flow. (CVRWQCB Staff report September 2003)

Sites in the eastside basin

East Valley Floor

STC 501-Harding Drain at Carpenter Road (TID lateral 5)

The Harding Drain is a site that is representative of a municipal and agricultural discharge in the area that drains directly to the SJR. The Harding Drain is a constructed, soft bottomed, channel, which carries discharges from the city of Turlock wastewater treatment plant (WWTP), storm runoff from the City of Turlock as well as agricultural tail water discharges and possible discharges and or seepage from confined animal facilities. The channel is deeply incised and completely channelized with no riparian zone.

Merced River Watershed

MER 581 Merced River at Hwy 59

The Merced River at Hwy 59 contains mostly clean cold water from Lakes McClure and McSwain. The site is upstream from most major agricultural influences, however it is down stream from a large gravel mining operation. The site is also directly down stream from a major stream channel, rehabilitation project and it is hoped that positive affects can be seen over time. The streambed is mainly large cobble and gravel. The site should also be directly comparable to the Mokelumne, and Cosumnes River sites.

MER 579 Ingalsby Slough @ J 17

Ingalsby Slough is small agricultural dominated channel receiving tail water from a verity of field and row crops. Ingalsby discharges to the Merced River downstream of the Hwy 59 site. The slough banks are well vegetated and the channel substrate is predominantly fine organic matter. Sediment load reduction Best Management Practices have been instituted in the area and are comprised mostly of grower education programs.

MER 580 Merced River at J16 Oakdale Rd.

This site is several miles down stream of the Hwy 59 site, and is one of the first sites were the Merced River begins to get agricultural influences. The substrate is mostly cobble with larger proportions of gravel and sand than at Hwy 59.

MER 546 Merced River at River Road

The Merced River at River Road is the last sampling site on the Merced River before it's confluence with the San Joaquin River. The stream receives agricultural discharges from field and row crops as well as orchards and wastewater treatment plants. The stream banks are well vegetated and the channel substrate is almost exclusively sand. The Merced River in the River Road area is 303 (d) listed for a variety of pollutants including organophosphate pesticides.

Southeast Basin

The South East Basin reaches from the SJR in the south up to the watershed divide between Bear Creek and the Merced River in Merced Co. to the north. The SJR upstream of the Mendota Pool is typically dry for most of the year due to agricultural diversions. Most of the water in this sub-area enters at the Mendota Pool, an in-stream impoundment, which receives agricultural supply water from the Delta Mendota Canal (DMC) as well as some upstream releases during extreme rainfall events or diversions from the Merced River. The majority of the water released from the Mendota Pool and irrigation return flows, are diverted out of the lower SJR at Sack Dam for irrigation supplies. The lower SJR is usually dry from Sack Dam until near where it reaches the Eastside Bypass and Bear Creek, which are the main SJR tributaries that drain this sub-area. Including agricultural supply and return flows, this sub-area accounts for approximately 23 percent of the SJR flow at Vernalis. (CVRWQCB Staff report September 2003)

Sites in the southeast basin

MER 007-Bear Creek at Bert Crane Road

Bear Creek is a sandy bottomed, modified, natural eastside creek that receives the majority of its flow from Burns and Bear Reservoirs via the Merced River. The channel is deeply incised and has a narrow but diverse riparian zone. Bear Creek at this point carries both irrigation supply water and return flows from varying crop types, as well as seasonal discharges from heavy storm events. Bear Creek flows to the East Side Bypass which then discharges into the SJR upstream of the town of Stevenson.

Grassland Watershed

The Grassland Watershed is located on the southwest side of the SJR basin. The majority of the water in this area originates in the Delta and is delivered via the DMC for agricultural use. This 871,000-acre area contains an 115,000-acre portion of the Grasslands Ecological Area (GEA), which is made up of private, State, and Federally owned and operated wetlands. The soils in this area are from rocks of marine origin and are very high in salts, boron and selenium. As a result of the high amount of salts and the intensive agricultural practices in the area, elevated electrical conductivity, selenium, and boron concentrations occur in these waters. This led to a selenium control program to be developed in the Drainage Project Area (DPA), 97,000 acres of agricultural area drained by subsurface tile drains. The control program has led to intense management of all drainage within the basin. The Grassland sub-area contributes around 6 percent of the lower SJR total flow at Vernalis. (CVRWQCB, Staff report September 2003).

Sites in the grassland watershed

MER 531-Salt Slough at Lander Ave (Hwy 165)

Salt Slough is a high TDS perennial slough dominated by Agricultural return flows and wetland discharges. It has a soft mud and sand bottom with a natural channel that winds its way through private, State and Federal wetlands to its confluence with the SJR near the town of Stevenson. Salt Slough has a wide and diverse riparian buffer that is dominated by grasses. The Grasslands Bypass Project removed High EC tile water, from the 97,000 ac. Grasslands area, from Salt slough and put it into the San Luis Drain (SLD) where it discharges to Mud Slough before entering the SJR.

MER 554 Los Banos Creek at Hwy 140

Los Banos Creek at Hwy 140 contains water from several different types of discharges including field and row crops, different types of orchards from almonds to stone fruits, discharges from state, private and federal wetlands, and treated waste-water from the city of Los Banos. Garzas creek, which has a mix of agricultural supply and return water mixes with Los Banos Creek up stream of this site, and it ultimately discharges into Mud Slough North. The creek is narrow and incised and contains very little riparian vegetation except for grasses and tules. The channel substrate is predominantly mud and other soft organic material.

MER 536-Mud Slough North Up stream of the San Luis Drain (SLD)

Mud slough is a perennial slough dominated by high TDS agricultural drain water, seepage from surrounding wetlands and Agriculture lands and ground water accretions. During the spring, flows in Mud Slough are dominated by discharges from wildlife refuges and duck clubs. Mud Slough at this location is located within the Kesterson National Wildlife Refuge and has a soft mud bottom with some areas of sand and hardpan clay and marl. The channel is deeply incised in places and the wide riparian zone is dominated completely by grasses and small shrubs.

MER 542 Mud Slough North Down Stream of the San Luis Drain (SLD)

Mud Slough down stream of the SLD is physically very similar to the up stream site. The down stream site has a slightly higher percentage of sand substrate and less mud. The key difference is the discharge of the San Luis Drain into Mud Slough between these two sites. The SLD carries agricultural tile drain water, which is high in salt, selenium and boron from the grasslands area. The SLD was designed to remove this water from the surrounding wetland channels in the grasslands area for the protection of waterfowl.

Northwest Basin

This area encompasses the watersheds of the Westside creeks and is approximately 386,000 acres, contributing 6 percent of the total SJR flow. Land use in this sub-area is predominantly agriculture including; confined animal facilities, row crops and orchards, there are also several small municipalities. Creeks in this area are naturally ephemeral but valley floor sections are kept running through the traditionally dry summer months with irrigation supply and return water. Water in this sub-area is of relatively poor quality and is high in TDS. Irrigation supply water in this area comes from several different sources including the DMC, pumped ground water, and diversions from the SJR.

Sites in the northwest basin

STC 019-Orestimba Creek at River Road

Orestimba is one of the largest Westside tributaries. It is representative in terms of land use to other Westside agricultural dominated waterbodies and has large amount of historic monitoring data. Orestimba Creek at this site has a deeply incised channel with mostly soft mud bottom with some areas of fine gravel and a narrow but very diverse riparian zone. It appears to be a natural creek channel however some relocation/construction may have occurred in the past. There are several areas at this site where the banks have been stabilized with concrete riprap. Downstream of the Eastin Road under crossing to the SJR, the creek is dominated by agriculture return flows (tail water and operational spills from the CCID main canal). Flows from the coast range reach the area down stream of Interstate 5 only during high flow, winter runoff periods and large storm events.

STC 517-Orestimba Creek at Bell Road

Orestimba Creek at Bell Road is a hardpan channel with large cobble in some areas. The creek at this site does not receive tail water from upstream agriculture and only receives surface flow from the upstream watershed during high flow storm events although water remains at this site just below the DMC year around. The water is believed to be groundwater or subsurface flow from the upper watershed. The area around the sampling site appears to have been impacted by high storm flows in the 1997 storms and by mining sometime in the last 20 years. The channel is deeply incised and has a wide riparian zone but is dominated by grasses and very young trees and shrubs.

STC 516-Del Puerto Creek at Vineyard Road

Del Puerto is an agricultural dominated Westside tributary to the SJR. The Creek has been channelized or modified in almost its entire length down stream of the DMC for agricultural discharges and has a soft mud to hard packed small gravel bottom and little to no riparian zone. The creek is historically ephemeral in the valley floor reaches, but receives agricultural return flows and operational spills during the irrigation season. There are often agriculture return flows during the late fall through winter months depending on water year type and over winter crops.

STC 040-Ingram Creek at River Road

Ingram Creek is a natural ephemeral Westside tributary upstream of I-5and only carries water from its upper watershed for 2-3 months per year. The portion of the creek, down stream of the DMC was formerly a dry wash that has been straightened and channelized. The creek channel has a soft mud, sand, and small gravel bottom with little to no riparian zone. Ingram Creek carries mainly agricultural return flows during the irrigation season as well as some ground water seepage during winter and early spring.

Sacramento-San Joaquin Delta (Delta)

The Delta sub-area contains over 1000 miles of waterways and is defined as the area North of Vernalis on the SJR, South of the I Street Bridge on the Sacramento River, and the Antioch Bridge as the Western boundary. Water in the Delta comes from both the Sacramento and San Joaquin Rivers and has varying quality and Beneficial Uses.

Bioassessment sampling in the main Delta waterways will be preformed under a separate project using TMDL funds. The only site in the Delta sub-basin for this project is an "Urban Creek background" site.

Baseline Conditions for Future Urban Creek: Land use patterns in the basin are changing as traditionally rural and agricultural areas are developed into cities. A new city of approximately 55,000 people is slated for development north of Tracy California.

SJC 509-Mountain House Creek

Mountain House Creek was a naturally ephemeral stream that has been highly altered for use as an agricultural drain. It is a constructed channel with a soft mud bottom and a narrow strip of willows for a riparian zone. The last 3.5 mi. of the creek before emptying into Old River are dominated by agricultural return flows during the irrigation season mainly from alfalfa. As work progresses for the community of Mountain House, which will completely surround the creek, houses will replace the alfalfa fields that drain to the creek. The stream channel and riparian zone will be reconstructed and restored for recreational use including a green belt and a walking and bicycle path.

BMI field collection

BMIs were collected from each site using a multi-habitat sampling method outlined in the EPA's rapid bioassessment protocols (Barbour, 1999). Reach lengths were designated at 100 meters. This method entails partitioning out the existing reach habitat into five different categories if present. The five categories were hard substrate (e.g., cobble, riprap, gravel), snags, vegetated banks, submerged macrophytes, and fine sediments. For a category to be included, it must have comprised at least five percent of the available reach habitat. A total of twenty jabs (each jab sampling half a square meter) were partitioned out proportionally based on available habitat types. For example, if snags comprised fifty percent of the reach habitat and riffles comprised twenty percent, then ten jabs were taken in snag material and four jabs were taken in riffle areas. The remaining jabs (six) were taken in any other habitat type(s) present. Sampling always began at the most downstream section of the reach. Sample material was rinsed and transferred into a sample jar containing ninety five percent ethanol every few jabs, or as needed, to prevent the net from clogging. After all twenty jabs were collected and placed into the sample container the net was inspected for clinging organisms. Any organisms found were removed with forceps and placed into the sample container. If possible all twenty jabs were composited into a single sample container, which then received internal and external labels containing site name and location, site code, date, time, and sampler's initials. If multiple sample jars were used, each one received identical labeling with an alphabetical code (A, B, C, etc…) which was also noted in the sample log book.

For methods comparison analysis at two sites BMIs were also collected using a modified low gradient version of the California Stream Bioassessment Procedure (CDFG, 2003). Using the same reach BMIs were collected from three randomly chosen transects from all possible meter marks (one to one hundred). Within each transect three two square foot areas were sampled and composited into a sample container and preserved with ninety-five percent ethanol. Each sample received labels as above, with the addition of a transect number (1-3) and CSBP designation. CSBP samples were collected when the corresponding meter mark was encountered during the multi-habitat sampling so as not to disturb the organisms in the reach, and collected using a separate net.

Habitat assessments

For a more comprehensive understanding of spatial variations in BMI community structure/integrity and potential causes of biotic disturbances, semi-quantitative habitat assessments were conducted simultaneously with BMI collections. Physical habitat assessments were conducted at each site. These included two components: (1) the CSBP

Worksheet that focuses on water quality and habitat parameters at the individual riffle/transect level and (2) the US EPA nationally standardized Habitat Assessment Field Data Sheet (Barbour *et al.*, 1999) that targets habitat conditions along the entire reach. Each of these physical habitat assessments has a low and high gradient version. Riffle/transect data collected included depth, velocity, and substrate composition. These measurements were recorded as the mean of three transect measurements. Substrate composition was recorded as an observational estimate of percentages of mud (<0.2 cm), sand (<0.2 cm), gravel (0.2 to 5.0 cm), cobble (5.0 to 25.0 cm), boulder (>25.0 cm), and bedrock/hardpan (solid rock or clay forming a continuous surface). Substrate consolidation was determined to be 'loose', 'moderate', or 'tight'. Gradient (percent slope) was determined as the change in elevation between upstream and downstream ends of a sampling reach.

Reach habitat data included estimates of ten physical habitat parameters (epifaunal substrate, sediment deposition, channel sinuosity, riparian vegetative zone width, pool substrate, available cover, channel flow status, bank stability, pool variability, channel alteration, and vegetative protection). Each habitat parameter was scored from 0 – 20, divided into quartile categories of 'poor', 'marginal', 'sub-optimal', and 'optimal' scoring categories. Each habitat parameter is scored using semi-qualitative criteria (Barbour *et al.*, 1999). Canopy cover was estimated with a hand held densiometer. At high gradient (slope > 0.2) sites, gradient was measured using a stadia rod and a clinometer. GPS coordinates were recorded at the second riffle/transect of all sites for CSBP samples, or at the bottom of the reach for multi-habitat samples.

Water quality measurements

Water quality measurements were recorded prior to collection of BMIs at the second riffle/transect (CDFG, 2003). Measurements included pH, specific conductance (SpC), dissolved oxygen (DO), and temperature. Collection of water quality data occurred at the time of BMI sampling and on a fixed monthly monitoring program. Monthly monitoring consisted of SpC, DO, pH, temperature, hardness and alkalinity determinations as well as measurements of metals, nutrients, total organic carbon (TOC), and biochemical oxygen demand (BOD) throughout the study.

Metal concentrations in site water samples were determined according to US EPA method 200.7 at Twining Laboratory in Fresno, CA. Nutrients in these site water samples were analyzed at Twining Laboratory or under the direction of Dr. Randy Dahlgren at the University of California, Davis, Department of Land Air and Water Resources. Procedures followed were US EPA method 300 for nitrate and ortho-phosphate, 350.3 for ammonia, 4500 for total nitrogen (Kjeldahl), and 365.3 for total phosphorus. Ceriodaphnia LC50s for diazinon and chlorpyrifos were calculated as averages of multiple datapoints found in the EcoTox database <http://www.epa.gov/ecotox/>. For more information on water quality measurements see the Surface Water Ambient Monitoring Program Quality Assurance and Protection Plan.

Laboratory sub-sampling

In the laboratory, five hundred or three hundred organisms were sub-sampled and removed from each composited sample for multi-habitat and CSBP methods, respectively. The removed BMIs were used for taxonomic identification, metric analysis, and abundance estimations. Sub-sampling consisted of: (1) transferring each sample to a 500 µm sieve, gently rinsing to flush out fine particles, (2) removing large debris such as gravel, fresh leaves, and sticks after thoroughly inspecting for entangled BMIs, (3) submerging the sieve containing BMIs in a 2.5 liter container of water to homogenize the sample, (4) draining the sieve, and (5) inverting the sieve over a white tray with numbered grid lines. Samples were spread evenly over 5X5 cm grids so as to accommodate the entire sample volume. Grids to be examined by dissecting microscope were selected at random. BMIs were removed from grids and transferred to a vial containing 70% ethanol (EtOH) until a 300 count was achieved. The last grid examined to achieve the three hundred count was completely processed, with additional BMIs placed into an ‘extras’ vial. BMIs from the ‘extra’ vial are necessary for an accurate estimate of sample BMI abundance. Sample abundance was estimated as the total number of BMIs removed from a sample, divided by number of grids processed, multiplied by total number of grids covered by the sample.

Sub-Sampling is the procedure in which the BMIs were removed from the sample material in a systematic way for identification, metric analysis, and sample abundance calculations. For this study five hundred and three hundred BMIs were removed from multi-habitat and CSBP samples respectively. After retrieving a sample from storage, the internal, external, and unique identification number were checked against each other to verify the correct sample was being processed. The sample material was then placed into a five hundred micron sieve and gently rinsed free of alcohol and fine particles. If desired, the technician rinsed and removed any large debris such as gravel, sticks, and leaves after inspecting for entangled BMIs. The sample was then homogenized as best as possible by partially submerging the sieve into a tub of water and gently stirring the sample material around to distribute it evenly. The sieve was then removed from the tub, and excess water allowed to drain. The sample material was then emptied into one or more white gridded (2 x 2 inches) trays. Grids were randomly selected, the sample material from each grid placed into a Petri dish containing ethanol, and all BMIs were removed using a dissecting scope with 7x minimum magnification and placed into an ethanol filled vial. Grids were processed until the target number of BMIs was obtained. For abundance calculations, the last selected grid was always completely processed, and all BMIs over the target number placed into an "extra" vial. All processed sample material was transferred into a "remnant" jar for QA/QC procedures. Sample abundance was estimated as the total number of BMIs removed from a sample, divided by number of grids processed, multiplied by total number of grids covered by the sample.

BMI identification

Taxonomic identification followed level I taxonomic effort set forth by the California Aquatic Bioassessment Laboratory Network (CAMLnet). Most insect taxa were identified to genus, and if monotypic given a species name as well. Chironomids were identified to tribe and worms to family. Non-insect taxa were taken to genus if possible, or left at a higher resolution. The taxonomy process was performed by first emptying the sub-sampled BMIs into a small Petri dish and covering them with 70% ethanol. Individuals of each unique taxon were removed, enumerated, and placed into a vial. Each vial received a site label and taxon label. The number of individuals in each vial and the taxonomist's initials were recorded in pencil on the taxon label. All vials from each sample were bundled together to maintain a voucher collection for the project and data entry.

Data analysis

Multivariate and multimetric analyses were applied to investigate spatial and temporal variability in BMI communities. Relationships between community structure, a range of environmental variables describing habitat and water quality, and a number of widely used metrics indicative of BMI community integrity were also examined.

Community composition

Community composition was evaluated through multivariate methods and by calculation of metrics summarizing components of the BMI community. Thirty-seven metrics were calculated, focusing on taxa which existing evaluations of BMI communities have shown to be potential indicators of the extent of anthropogenic stress acting on benthic communities.

Community composition was probed by ordination with non-metric multidimensional scaling (NMS) to reveal the strongest patterns in BMI community structure across sites. NMS ordination created axes that summarize BMI assemblages based on the proportions of taxa at the sites. Correlations with these axes showed the strength and direction of associations between species composition, environmental variables, and metrics indicative of BMI community integrity.

Proportional abundance of taxa (# of individuals of a given taxon / total # individuals collected) was utilized when examining community composition, as opposed to estimated absolute abundance, because the BMI sampling and sample processing methods are not designed to determine actual abundances at a site. The proportional abundance data were arcsine-square root transformed to moderate the influence of common and rare taxa (McCune and Grace, 2002). Taxa occurring only at one site (rare taxa) were excluded from statistical analyses to improve resolution of commonalities among sites.

Ordination relies on calculation of a distance measure to quantify taxa composition similarities among sites. Sorenson distance, which has been shown to be a more accurate representation of community structure than Euclidean distance, was used as a measure of overall site similarity (McCune and Grace, 2002). Cluster analyses and ordinations were performed using PC-ORD 4.0 (McCune and Mefford, 1999).

Seasonal variation may influence diversity and abundance of BMI communities. We sought to control for this seasonal variation by performing separate ordinations of data collected during the spring and fall sampling events.

NMS ordination was applied to visualize the relative positions of the sites along gradients representing aspects of the benthic macroinvertebrate community structure. Sites with similar communities appear close to one another in the ordinations. NMS is well suited to summarizing nonlinear associations among the abundances of a large number of rare species (McCune and Grace, 2002). NMS is distance-preserving: it maintains the rank-order of dissimilarity values between the sites. It is an iterative optimization method that improves the fit of the ordination to the original distance matrix through a series of small steps, until a stable, well-fitting solution is obtained.

NMS was performed with random starting coordinates and a step length of 0.20. Forty starting configurations were used, and for each starting configuration solutions were computed using dimensionalities ranging from 2-6 dimensions. The lowest stress solution for each dimensionality (in which the distances in the ordination space most resemble the distances in the original distance matrix) was compared to the lowest stress solutions for the other dimensionalities. The solution chosen was the highest dimensionality solution with a final stress more than 5 units lower than the next lower dimension, provided that the solution had a stress lower than 95% of 50 solutions calculated at that dimensionality with randomized data (McCune and Grace, 2002).

NMS was selected in preference to canonical correspondence analysis (CCA) because in CCA the pattern of biological samples is constrained by the environmental variables included in the analysis. With NMS, measured environmental variables do not bias the ordination of biological data. This yields a more accurate picture of the overall community structure.

Taxonomic composition, environmental variables, and BMI metrics gradients

Pearson product-moment correlations between the NMS axes and taxa proportional abundance revealed the major taxonomic gradients represented by the axes. Correlations between these axes and environmental variables and BMI metrics indicative of community integrity indicated the strength and direction of environmental gradients (i.e., environmental parameters likely to be determinants of community structure) and gradients of BMI community integrity (i.e., indication of community structure changes relevant to community integrity/health) associated with each axis, respectively. Environmental variables examined include water quality parameters as well as measures of substrate and physical habitat.

For reference of those interested in the utility of a particular metric in examining potential effects of a particular stressor, we calculated Pearson product-moment correlations between environmental variables and BMI metrics.

Data variability and sampling method comparison

Evaluation of data variability seen in the field duplicate at Lone Tree Creek and method comparison with the CBSP was achieved by direct comparison of the metrics calculated in the relevant samples, and by plotting predicted NMS scores of the duplicate and CSBP samples on the existing NMS axes calculated using the multi-habitat dataset.

Results

Environmental data

Sites with a wide range of environmental conditions and habitat types were investigated, ranging from 1 meter wide agricultural tributaries with mud substrate and conductivity readings (EC) above 3000 µmhos to riffle-dominated rivers approaching 50 meters in width where EC was below 100 µmhos. Dissolved oxygen (DO) tended to be fairly high (> 6.0 mg/L), and was unlikely to present a major stressor to the benthic macroinvertebrates at the sites examined. Dissolved minerals, metals, nutrients, and organic carbon were present at elevated levels in some samples. Substrate and instream habitat varied between narrow, straight channeled sites dominated by mud and sand to wider waterways containing many riffles and cobble substrates. The ranges and mean values of quantitative and ordinal environmental variables are summarized in Table 2.

Insecticide data collected during 2001 and 2002 at a small number of sites show a range of concentrations. Insecticide monitoring data including measurements of diazinon during 2001 and 2002 and chlorpyrifos during 2002 show long periods of low concentrations marked by occasional high spikes, some of which exceed *Ceriodaphnia* LC50s (Figures 2 and 3). Chlorpyrifos data from Del Puerto Creek were the exception (Figure 3). At this site, 44% of measurements of chlorpyrifos concentrations recorded between May 2002 and August 2002 exceeded 0.01 ppb (0.2 TUs for *Ceriodaphnia* acute mortality; seven of 16 observations).

Benthic macroinvertebrate communities

Metrics summarizing BMI community components revealed that fauna was dominated by multivoltine taxa that feed on fine particulate organic matter (FPOM). These taxa are capable of quickly re-establishing populations after local extinctions, and thrive in the absence of solid substrates. Number of taxa observed at a site ranged from 10 to 27, and the percent insects varied from less than 10 to near 100 percent. The percent BMI community composed of amphipods varied from 0 to 40 percent, while the percent oligochaetes varied from 0 to 80 percent. Both amphipods and oligochaetes are able to live in soft, unstable substrate. Amphipods tend to be somewhat sensitive to water quality, while oligochaetes are highly tolerant of poor water quality. No major taxonomic shifts were seen between the spring and fall samples (Figure 4).

Associations of BMI community differences with environmental parameters

Figures 5 and 6 depict NMS ordinations of BMI community data collected in spring and fall, 2002. Sites in close proximity on these plots possessed similar BMI communities, while sites with less similar BMI communities are farther apart. Each axis represents a gradient in BMI community structure comprised of a correlated set of changes in BMI taxa abundance. The figures each illustrate two different views of a three dimensional ordination, and highlight the environmental variables significantly correlated with each ordination axis. Tables 3 and 4 depict environmental variables, BMI metrics, and BMI taxa most strongly correlated with the NMS axes during each sampling event. Appendix A provides correlation values between environmental variables and individual BMI metrics. These correlation values are useful in determining utility of a particular metric in assessing potential stressors.

Spring BMI communities

During the spring sampling event, only the first NMS axis was strongly correlated with a suite of environmental variables and BMI metrics (Figure 5 and Table 3). This axis ordinated communities grading from oligochaete-dominated assemblages of pollution-tolerant taxa to more diverse insect-dominated assemblages consisting of more pollution-sensitive taxa. Many correlated potential stressor variables were associated with low scores on this axis, including erosion and mud dominated substrate, high nutrients, irrigation return water, and agricultural land use. Taxa most strongly correlated with potential stressors and less diverse communities were the tubificid and nematode worms. Taxa most strongly correlated with more diverse communities included a number of Ephemeroptera (mayfly) and Trichoptera (caddisfly) taxa, as well as chironomids (Diptera) of the tribe Tanytarsini and amphipods of the genus *Crangonyx*.

Abundance of many taxa were correlated with NMS axis 2, including more insects and *Hyalella* amphipods towards the negative end of the axis and more *Corophium* amphipods towards the positive end of the axis. However, this axis did not correlate strongly with suites of environmental variables (to indicate possible causes of community differences) or BMI metrics (to summarize community differences). Axis 3 did not correlate strongly with many environmental variables, BMI metrics, or BMI taxa.

Fall BMI communities

Table 4 summarizes the environmental variables, BMI metrics, and BMI taxa most strongly correlated with each NMS axis for the fall sampling event (Figure 6). This ordination may allow more discrete associations between environmental variables and taxonomic differences than the ordination of the spring data, because a different suite of environmental variables was correlated with each NMS axis.

Axis 1 appears to be less associated with environmental variables than the other two axes. Rather, it captures community differences associated with varying levels of flow. Low flow volume sites, appearing towards the negative end of axis 1, were distinguished by large amounts of detritus, sand, macrophytes, and organic muck (FPOM). These sites had more FPOM consumers, more chironomids, and more amphipods, as well as more organic pollution-tolerant taxa. Certain Ephemeroptera and chironomids were the taxa most strongly associated with low flow sites, while filter feeding *Simulium* (black fly larvae) was associated with high flow sites.

Axis 2 was associated with water quality variables, including arsenic and nutrients, which increased toward the positive end of the axis. Some measures indicating habitat quality increase towards the negative end of the axis. The diversity and abundance of many larval insects were negatively correlated with this axis. Agriculture-dominated waterway communities tended to score higher on this axis than river communities, but there was overlap between creeks/drains and rivers along the axis. Del Puerto Creek, Ingram Creek, and Harding Drain were the agriculture-dominated waterways that scored highest on this axis; Cosumnes River sites were the highest scoring river sites. Therefore, these are the sites in each category most likely impacted by water quality variables.

Axis 3 was primarily associated with habitat variables, representing a gradient from mud-dominated pool habitats at the positive end of the axis to cobble-dominated riffle habitats at the negative end of the axis. Ephemeroptera, pollution-sensitive EPT, and univoltine taxa metrics exhibited the strongest negative correlations with this axis, while multivoltine, pollution-tolerant, and oligochaete taxa abundance manifested the strongest positive correlations. A large number of agriculture-dominated waterways scored high on this axis. These sites were dominated by fine substrates and were characterized by organisms accepting of such substrates, including worms and chironomids. The agriculture-dominated waterway sites scoring highest on this axis are likely more subject to sedimentation than other sites examined.

Spatial patterns and upstream-downstream comparisons

Table 5 summarizes proportional abundances of key BMI community components at sites during each sampling event. These measures are useful for comparing BMI communities of different sites, and for detecting major differences in BMI communities along individual waterways. The NMS analyses demonstrated that these proportional abundance measures summarize and are correlated with major components of variation in the BMI community. Further, these measures likely reveal anthropogenic stress over the range of sites. Refer to Figure 1 for locations of sites and waterways discussed.

%EPT: Most EPT taxa are predominantly riffle-dwelling contaminant sensitive organisms. EPT taxa (%EPT) proportional abundance showed a wide variation among the riffle-containing sites. This variation may be due to differences in the benthic habitats sampled, or differences in water quality between sites.

% Other (non-EPT) insect and amphipod taxa (%IA): Non-EPT insects and amphipods show a wide range of pollution-tolerance levels, but are more pollution-sensitive than most non-insect taxa in the BMI community. Non-EPT insect and amphipod taxa (%IA) proportional abundance varied considerably among sites on agricultural waterways; EPT taxa diversity and abundance were low at sites on these waterways.

% Non-insect non-amphipod taxa (%NIA): Taxa that are neither insects nor amphipods form the most pollution-tolerant component of the BMI community.

River Communities

The upstream sites on the Merced River (MER581 and MER580) manifested the highest %EPT. In spring, the other sites on rivers consisted of approximately equal %EPT. In fall, the Cosumnes River sites (SAC003 and SAC004) had lower %EPT, whereas %EPT was slightly higher at Mokelumne and Calaveras River sites (SJC512 and SJC514). During fall sampling event, the Cosumnes River was shallow and very warm compared to other rivers, which may explain the low %EPT.

During both sampling events, the site on the Cosumnes River downstream of Rancho Murieta (SAC004) revealed lower %EPT, higher %IA and %NIA, compared to the upstream site (SAC003). This change in the BMI community indicates that factors associated with the city or upstream cattle grazing may be reducing the river's capacity to support pollution-sensitive taxa.

MER580, downstream of the confluence of the Merced River and Ingalsbe Slough, had a higher percent insects and amphipods than the upstream site (MER581), suggesting little or no BMI community degradation from input from the agricultural slough. The farthest downstream site on the Merced River (MER546) is 303(d) listed for pesticide contamination. This site exhibited lower EPT abundance than the upstream sites during both sampling events. However, a considerable portion of the BMI community at this site was composed of EPT and other insects, indicating that potential pesticide contamination was not severe enough to extirpate EPT or other insect populations.

Agricultural Stream Communities

All communities in agriculture-dominated waterways, except the upstream site (above agricultural inputs) on Orestimba Creek (STC517), were characterized by very low %EPT. Most of these waterways manifested high %IA. Abundance of all insect and amphipod taxa, including generally pollution-tolerant chironomids, were low at a few sites indicating possible contamination severe enough to prevent large populations of aquatic insects. These sites included Ingram Creek and Mountain House Creek in spring (STC040 and SJC509), and Harding Drain, Del Puerto Creek, Ingram Creek, and Lone Tree Creek in fall (STC501, STC516, STC040 and SJC503).

During both sampling events the downstream Mud Slough site (MER542) consisted of a higher %NIA than the upstream site (MER536). Further, the insect community of the downstream site was dominated more by chironomids than the upstream site. These findings indicate that factors associated with San Luis Drain input may compromise the ability of Mud Slough to support more pollution-sensitive insect and amphipod taxa.

The BMI community at the upstream Orestimba Creek site (STC517) differed greatly from the community at the downstream site (STC019). The upstream site (above agricultural input) was dominated by *Caenis* mayflies, while the downstream site contained mainly non-insect organisms and chironomids. Although the substrates of the two sites were similar, clear water and low flow velocities were present at the upstream site, while turbid conditions and faster flows were characterized the downstream site. Agricultural inputs likely result in water quality changes that impact the BMI community at the lower site.

French Camp Slough is downstream of Lone Tree Creek, but the fauna at both sites varied radically between sampling events, rendering comparison of the two sites difficult. A large population of *Simulium* (larval black flies) was noted at Lone Tree Creek in spring, but was characterized by few larval insects in fall. In contrast, the French Camp Slough site manifested mainly chironomids and non-insects in the spring, but had a large population of *Hydropsyche* (mayflies) in fall.

Data variability and comparison of low gradient modified CSBP and multi-habitat sampling methods

During the fall sampling event, two simultaneous multi-habitat samples were taken at Lone Tree Creek (SJC503). BMI taxa diversity and abundance at the site were similar in the two samples (Table 6). The major difference was a markedly higher tubificid worm abundance in the duplicate sample (reflected by a dramatic increase in percent Oligochaeta and percent collectors, and in a large decrease in percent filterers). Most metrics were not noticeably affected by this difference. Variation between spring and fall BMI samples from a given site was generally low (Table 5). The high variation between the fall Lone Tree Creek sample and its duplicate was likely, therefore, an anomaly. Including the Lone Tree Creek duplicate in a fall sample cluster analysis allowed an estimate of our sampling method resolution and ability to detect site to site differences. The Lone Tree Creek primary sample appeared to bear as much similarity to samples from a number of other agriculture-dominated waterways as to duplicate sample taken simultaneously (Figure 7).

Also during the fall event, the Lone Tree Creek and French Camp Slough sites (SJC503 and SJC504) were sampled simultaneously with the low gradient modified CSBP (LGCSBP) and multi-habitat sampling protocols. A comparison of BMI metrics between the two sampling protocols suggested that the LGCSBP detected greater taxonomic diversity (Tables 6 and 7). This detection of greater taxonomic diversity was maintained irrespective of metrics recalculation from sub-samples of 500 specimens chosen randomly from the 900 specimen LGCSBP samples. Metrics summarizing taxon proportional abundance did not appear to depend on sampling protocol. Figure 7 illustrates taxonomic difference between multi-habitat and LGCSBP samples collected at the same site relative to the degree of taxonomic difference between sites.

Discussion

Between site comparisons of BMI communities

Sites sampled in this investigation can be divided into those sites on rivers that contained some riffle habitat and those in agriculture-dominated waterways did not contain riffle habitat. The sites on rivers manifested a wide variation in percent EPT taxa in the community. Upstream sites on the Merced River (MER580 and MER 581) had the highest percent EPT, while the lowest percent EPT among river sites was seen in the Cosumnes River during a fall period of shallow, warm conditions. The sites in agriculture-dominated waterways contained few EPT, but exhibited wide variation in percent total insects and amphipods. Amphipods were included in this measure because they are often used as subjects of toxicity tests (e.g., *Hyalella* and *Gammarus*), and are sensitive to many contaminants (Cold and Forbes, 2004; Schroer et al., 2004). Most agriculture-dominated waterway sites were characterized by sizable larval insect populations. Notable exceptions, dominated by non-insects at times, included Ingram Creek (STC040), Mountain House Creek (SJC509), the Harding Drain (STC501), Del Puerto Creek (STC040) and Lone Tree Creek (SJC503). This lack of insects cannot be completely attributed to poor habitat, since chironomids often inhabit depositional environments of fine substrate. Samples with an absence of insects may indicate contaminated water or sediment. More research is needed, however, to ascertain if either the life cycles of indigenous species or the periodic desiccation of ephemeral waterways could cause an absence of insects to be a part of natural temporal variation in aquatic communities.

Some comparisons of sites along the same waterway revealed a loss of pollution-sensitive taxa at downstream sites. This was the case on the Cosumnes River, Orestimba Creek and Mud Slough. On the Cosumnes River, inputs from the community of Rancho Murieta may contribute to this loss of pollution-sensitive taxa. On Orestimba Creek, influences on the downstream fauna included inputs from row crops and orchards. On Mud Slough, the downstream site received water from the San Luis Drain, which may have affected BMI community composition. Loss of pollution-sensitive taxa was not observed either at the two upstream sites on the Merced River or at the Lone Tree Creek and French Camp Slough sites. Percent EPT taxa was lower at the most downstream Merced River site than at the upstream sites, but the downstream site consisted of more sand and less gravel and cobble than the upstream sites, and was therefore, less favorable for habitation by most EPT taxa.

Correlations between BMI communities and environmental variables

The spring dataset consisted of one major gradient in BMI community structure which was correlated with many environmental variables and associated with changes in several BMI community metrics. The fall dataset revealed three separate BMI community gradients, each correlated with a separate set of environmental variables, and associated with somewhat different (compared to spring) sets of BMI metrics. The two major BMI community composition gradients (Fall Axis 1 and Fall Axis 2 that summarized 35.8% and 36.7% of the variability in BMI communities, respectively) appeared to be associated with 1) flow and 2) nutrients and arsenic. The sites with the least diverse communities and the lowest percent insect taxa tended to be characterized by higher nutrient or arsenic concentrations. The third BMI community composition gradient (Fall Axis 3, 11.6% of the variability) was associated with physical habitat, TOC, and zinc. BMI community composition did not show a clear relationship to local agricultural land uses (row crops, orchards, or pasture) during either sampling event. Other environmental variables not considered by this study may drive or contribute to the observed correlations with community structure.

Relative to BMI data collected in June and September 2001 at many of the same sites (de Vlaming et al., 2004b), current results suggest that many of the same environmental factors determine BMI community composition. However, in this investigation environmental variables were not correlated to one another in the same ways as in the earlier study. Compared to data collected in the 2001 study, the 2002 dataset revealed weaker correlations between metals and BMI communities, but stronger associations between community composition and channel flow variables. The strong relationships with channel flow seen in 2002 may be related to the greater number of sites on river channels. Reasons for the weaker relationship between metal concentrations and BMI community structure are not clear. Data collected in both years indicated that physical habitat quality is an important determinant of BMI diversity. Significant relationships between several water quality factors, including nutrients and TOC, and BMI community composition (low biodiversity) were seen in both years.

Detection of associations between BMI community and various environmental variables fits into a framework outlining cumulative anthropogenic impacts on habitat and water quality. Cumulative and interacting anthropogenic stressors that affect aquatic biota include alterations of the following (Karr, 1991; Karr and Yoder, 2004):

1. Energy Source
2. Chemical variables
3. Flow regime
4. Habitat structure
5. Biotic factors (including predator-prey and competitive interactions).

In the Clean Water Act §502(19), the effects of pollutant substances as well as nonpollutant stressors such as flow alteration, loss of riparian zone, physical habitat degradation, and introduction of alien taxa are all considered pollution and, thus, subject to regulation (Karr and Yoder, 2004). Data collected in this study and two earlier studies (de Vlaming et al., 2004a, b) illustrate that all five types of alterations to aquatic communities are likely to be widespread in the Central Valley.

Contamination signatures

The ability to distinguish contaminant-related from other stressor impacts would be of considerable value in evaluating causes of non-attainment of aquatic life beneficial uses. A limitation of bioassessment, however, is the inability to directly identify cause(s) of impact/impairment (e.g., Barbour et al., 1996; Clements and Kiffney, 1996; Holdway, 1996; McCarty and Munkittrick, 1996; Wolfe, 1996; Power, 1997; Bart and Hartman, 2000; Adams, 2003). An integrated monitoring/weight-of-evidence approach is preferred for identification of impacts/impairment and cause(s) thereof (e.g., Taylor and Kovats, 1995; Culp et al., 2000; National Research Council, 2001; Collier, 2003; Hewitt et al., 2003; de Vlaming et al., 2004a).

As a result of integrated toxicological and community studies, Yoder and Rankin (1995) reported that BMI communities lacking most insect taxa, including an absence of chironomids (usually ubiquitous in low gradient systems), tended to be associated with toxic conditions. The work presented here supports this finding. During each 2002 sampling event in the San Joaquin River watershed some sites, including Del Puerto Creek (STC516), had very few insects (Figures 5 and 6). Chlorpyrifos concentrations in Del Puerto Creek frequently approached the *Ceriodaphnia* LC50 (Figure 3). At the same site in Del Puerto Creek, Domagalski and Munday (2003) reported chlorpyrifos concentrations twice the *Ceriodaphnia* LC50 during early May 2001. Sediment toxicity samples taken in October 2001 by the Surface Water Ambient Monitoring Program in Del Puerto Creek resulted in 100 percent mortality to *Hyalella azteca* (Phillips 2002). A toxicity identification evaluation (TIE) and chemical analysis on sediment collected from Del Puerto Creek in June and September, 2002 suggest pyrethroid insecticides as the cause of toxicity. Chemical analysis revealed 43.2 ng bifenthrin/g dry sediment weight and 20.4 ng permethrin/g dry sediment weight in June samples and 7.51 to 8.25 ng bifenthrin/g dry sediment weight in September samples. The June samples also contained 0.056 µg/L chlorpyrifos and 0.047µg/L diazinon. Several organochlorines also were identified in the pore water and sediment of the June sample, most notably DDE, p,p' at 39.5 ng/g in sediment (Phillips 2002).

Del Puerto Creek and the other sites with insect-poor communities are candidates for further investigation and possible contaminant mitigation actions. Other sites located in close proximity to insect-poor sites on the NMS axes (Figures 5 and 6) also may bear the toxicity signature, though to a lesser extent. Among spring samples (Figure 5) the sites exhibiting a paucity of larval insects clustered at the negative end of axis 1. One possible interpretation is that the other sites positioned towards the negative end of the NMS axis were contaminant impacted, but to a lesser extent.

Among fall samples, Del Puerto Creek (STC516) and Ingram Creek (STC040) contained very few insects (Figure 6). *Hyalella* acute sediment toxicity was noted in several Ingram Creek samples following BMI sample collections for this project (Phillips 2002). TIEs point to multiple pyrethroid pesticides as the cause of toxicity. Other sites that positioned towards the positive end of NMS axis 2, along with the Del Puerto Creek and Ingram Creek sites, may have been contaminant impacted.

The sites included in this project are subject to multiple stressors (e.g., flow alterations, contaminant pulses, etc.) and contain communities comprised of multivoltine organisms able to quickly re-establish populations after toxic events. Among these impacted communities it appears to be possible to detect contaminant signatures. Weight-of-evidence investigations combining BMI bioassessments and toxicology have proceeded to the point where we can now rely on the results of past work to calibrate probable toxicological implications of particular BMI community profiles. While evaluations of ecological health must continue to include multiple lines of evidence from water chemistry, toxicology, and bioassessment, the existing body of integrative research greatly increases the utility of bioassessments in the preliminary identification of sites most likely to be impacted by particular stressors.

Data variability and comparison between methods

The duplicate multi-habitat sample collected at Lone Tree Creek during fall sampling event suggests that variation between multi-habitat replicates at Lone Tree Creek (SJC503) was greater than variation in BMI communities between some sites. Therefore, the communities at a number of sites examined were too similar for the reliable detection of between-site differences by the multi-habitat sampling procedure (Figure 7). This result is contradicted to some extent by the similarity in community composition seen between fall and spring samples taken at most sites. Replication at a greater number of sites is desirable in order to further quantify the precision of the multi-habitat rapid bioassessment protocol. Between-site differences may be especially difficult to detect when biodiversity is low, as is the case in the agriculture-dominated waterways of the Central Valley.

Samples collected according to the LGCSBP at Lone Tree Creek and French Camp Slough both showed higher diversity, but roughly similar taxonomic composition, compared to the multi-habitat samples collected at the same time (see Tables 6 and 7, Figure 7). This heightened diversity in CSBP samples was observed even after the size of each sample was randomly reduced to 500 organisms to match the multi-habitat samples. This finding is unlikely due to species/area relationships because these methods sample similar areas of substrate (LGCSBP: 9 jabs x 2 ft^2 = 18 ft^2; Multi-habitat: 20 jabs x 1 ft^2 = 20 ft^2). The difference in estimated diversity may have been haphazard as a consequence of high variability of BMI samples (variability among rapid bioassessment replicates is typically high—e.g., Barbour et al., 1992; Resh, 1994; Hannaford and Resh, 1995) collected or caused by the larger number of CSBP sampling "jabs" collected in close proximity to stream banks. While "jabs" in the multi-habitat method are collected in proportion to the quantity of each habitat type at a site, a CSBP sample consists of three transects, each of which is made up of one "jab" in the thalweg, and two "jabs" near the banks of the stream, so six out of nine CSBP "jabs" are likely to be taken near the banks. When a site has very poor instream habitat, the greater portion of the taxa at the site are likely to occur near the banks (Roy et al., 2003) and, thus, more likely to be collected by the CSBP approach.

Summary

Benthic macroinvertebrate bioassessment revealed a wide range of BMI community types in agriculture-dominated waterways of the San Joaquin River watershed. Anthropogenic stressors including nutrients, total organic carbon, and poor instream habitat correlated with differences in BMI communities. The least diverse communities contained few larval insect taxa and low chironomid abundance, which may consequent to recurring toxicity. In cases where multiple sites were sampled on the same waterway, downstream sites sometimes displayed a loss of pollution-sensitive taxa compared to upstream sites. Stressors associated with the loss of pollution-sensitive taxa varied from waterway to waterway, and included urban land use, agricultural land use, and poor instream habitat. Multivariate analyses revealed other sites with community characteristics similar to these least diverse sites. Some sites consisted of communities too similar to be differentiated by the multi-habitat bioassessment protocol used. At two sites sampled by the multi-habitat protocol and the CSBP, the CSBP sample yielded greater taxonomic diversity even after its sample size was reduced to be comparable to the multi-habitat sample.

Acknowledgements

Funding for this project derived from Central Valley Regional Water Quality Control Board monies from the Surface Water Ambient Monitoring Program. Jay Rowan served as the Regional Board project manager for this project. Field assistance was provided by the SWAMP program.

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Table 1. Locations and codes of sampling sites in the San Joaquin River watershed.

Site Name	Site Code	Latitude	Longitude	Ecoregion
Bear Creek @ Bert Crane Rd.	MER007	37.2556	-120.6519	Manteca-Merced Alluvium
Salt Slough @ Lander/Hwy 165	MER531	37.2486	-120.8511	San Joaquin Basin
Mud Slough Up Stream of SLD	MER536	37.2550	-120.8742	San Joaquin Basin
Mud Slough Down Stream of SLD	MER542	37.2625	-120.9056	San Joaquin Basin
Merced River @ Hatfield Park (River Rd)	MER546	37.3497	-120.9578	San Joaquin Basin
Los Banos Creek @ Hwy 140	MER554	37.2764	-120.9539	San Joaquin Basin
Ingalsby Slough @ J17 Turlock	MER579	37.4918	-120.5578	Hardpan Terraces
Merced River @ J16 Oakdale Rd.	MER580	37.4540	-120.6092	Manteca-Merced Alluvium
Merced River @ Hwy 59	MER581	37.4702	-120.5005	Manteca-Merced Alluvium
Cosumnes R. @ Michigan Bar Rd.	SAC003	38.5006	-121.0450	Camanche Terraces
Cosumnes River @ Hwy 16	SAC004	38.4904	-121.0978	Camanche Terraces
Lone Tree Creek @ Austin Rd.	SJC503	37.8556	-121.1847	Delta Basins
French Camp Slough @ Airport Rd.	SJC504	37.8817	-121.2492	Delta Basins
Bear Creek @ Lower Sacramento Rd.	SJC515	38.0431	-121.3486	Delta Basins
Mtn. House Creek @ Byron Rd.	SJC509	37.7856	-121.5356	Westside Alluvial Fans &Terraces
Mokelumne R. @ Van Assen Co. Park	SJC512	38.2225	-121.0344	Camanche Terraces
Calaveras River @ Shelton Rd.	SJC514	38.0727	-120.9310	Camanche Terraces
Orestimba Creek @ River Rd.	STC019	37.4139	-120.0142	Westside Alluvial Fans & Terraces
Ingram Creek @ River Rd.	STC040	37.6003	-121.2242	Westside Alluvial Fans & Terraces
TID 5/ Harding Drain @ Carpenter Rd.	STC501	37.4644	-120.0303	Caswell Basin
Del Puerto Creek @ Vineyard	STC516	37.5214	-121.1486	Westside Alluvial Fans & Terraces
Orestimba Creek @ Bell Rd.	STC517	37.3458	-121.0792	Westside Alluvial Fans & Terraces

Table 2. Ranges and means of environmental variables measured during the spring 2002 and fall 2002 sampling events. Trend monitored water quality variables were averaged at each site over the three months preceding each sampling event.

	Spring				Fall			
	Lowest Site Average	Mean	Highest Site Average	# Sites	Lowest Site Average	Mean	Highest Site Average	# Sites
Temp (C)	10.8	15.8	18.5	15	14.0	21.4	25.1	16
pH	7.4	7.9	8.3	15	7.1	7.8	8.3	16
DO (mg/L)	6.3	8.8	11.0	14	3.1	6.9	8.8	15
Field EC (umhos)	41.9	979.2	4248.9	15	51.5	735.3	3191.5	16
HDNS	45	176	520	8	38	181	470	12
Alkalinity (mg/L)	44	99	230	8	31	103	200	8
TDS	92	696	1785	7				
Sodium (mg/L)	5.2	152.7	651.3	13	4.0	111.4	487.0	13
Potassium (mg/L)	0.9	4.5	9.1	14	0.8	4.5	7.9	14
TSS	1.9	31.5	81.4	3				
Se	0.0	8.6	40.6	5	0.0	5.1	28.4	6
Mo	0.8	8.6	14.9	5	0.0	3.9	10.8	4
Cr	0.0	3.0	18.2	12	0.0	3.6	13.0	12
Cu	2.9	4.5	9.8	12	2.7	5.6	8.0	4
Ni	0.0	5.5	29.3	12	0.0	4.4	18.0	12
Pb	0.0	0.3	3.3	12	0.0	0.0	0.0	12
Zn	3.1	7.9	31.0	12	0.0	7.6	20.0	12
Total Cadmium (ug/L)	0.0	0.0	0.0	12	0.0	0.0	0.0	11
Total Arsenic (ug/L)	0.0	1.7	6.9	12	0.0	3.3	7.9	12
B	0.0	1.0	5.4	11	0.0	0.7	5.2	12
Cl	3.9	137.7	487.2	13	3.2	122.5	424.9	13
SO4	4.8	242.3	1429.6	13	4.0	141.6	1054.6	13
Kjeldhal N (mg/L)	0.10	1.10	2.09	8	0.08	2.71	15.70	9
Nitrite + Nitrate (mg/L)	0.05	1.24	5.51	10	0.03	2.15	11.55	10
Nitrate N (mg/L)	0.67	3.71	11.14	5	0.56	3.52	7.74	5
TotalP (mg/L)	0.02	0.25	0.56	13	0.06	0.32	1.11	14
Ammonia N (mg/L)	0.00	0.11	0.37	14	0.00	0.22	1.37	15
BOD5 (mg/L)	1.2	2.7	5.8	12	0.4	2.0	4.1	13
BOD10 (mg/L)	2.1	4.5	9.7	12	0.8	3.9	6.9	13
TOC (mg/L)	3.2	7.7	19.0	9	2.9	4.0	4.7	5
96h FHM surv (%)	90	97	100	4	93	97	100	5
48h Cerio surv (%)	0	75	100	4	70	93	100	5
Elev (ft)	15	100	181	19	15	100	181	19
Cobble Habitat (%)	0	13	60	20	0	13	60	20
Snag Habitat (%)	0	7	20	20	0	7	20	20
Veg. Banks Habitat (%)	0	12	40	20	0	12	40	20
Sand Habitat (%)	0	24	60	20	0	24	60	20
Macrophyte Habitat (%)	0	2	15	20	0	2	15	20
Gravel Habitat (%)	0	11	35	20	0	11	35	20
Mud Habitat (%)	0	21	95	20	0	21	95	20
Local NPS Pollution	1	1.7	2	19				

(continued)

(Table 2 cont'd.)

	Spring				Fall			
	Lowest Site Average	Mean	Highest Site Average	# Sites	Lowest Site Average	Mean	Highest Site Average	# Sites
Erosion	1	1.5	2	18				
Width (m)	1.0	15.3	40.0	19	1.0	15.3	40.0	19
Depth (m)	0.1	0.8	2.0	17				
High Water Mark (m)	0.5	2.1	6.0	15	0.5	2.1	6.0	15
Riffle (%)	0	18	80	20	0	18	80	20
Run (%)	0	39	100	20	0	39	100	20
Pool (%)	0	43	100	20	0	43	100	20
WaterOils	0.0	0.1	2.0	21				
Sediment Oils	0.0	0.1	2.0	21				
Boulder (%)	0	1	10	19				
Cobble (%)	0	11	60	19				
Gravel (%)	0	14	50	19				
Sand (%)	5	33	80	19				
Silt (%)	3	16	45	19				
Clay (%)	2	12	45	19				
Detritus (%)	0	15	45	18				
Muck (%)	0	16	80	18				
Marl (%)	0	0	2	18				
Epifaunal Substrate	4	10	18	21				
Pool Substrate	7	11	18	21				
Pool Variability	6	11	17	21				
Sediment Deposition	4	9	17	21				
Channel Flow	5	14	18	21				
Channel Alteration	2	12	19	21				
Channel Sinuosity	2	10	18	21				
Bank Stability	4	10	16	20				
Vegetated Banks	5	10	16	21				
Riparian Zone Width	2	9	19	21				

Table 3. Environmental variables and benthic macroinvertebrate metrics significantly correlated with the axes of the NMS ordination performed on the spring 2002 BMI data ($P < 0.05$), along with taxa correlated with the axes ($|r| > 0.400$). Shading indicates negative correlations.

	Environmental Variables				Metrics				Taxa	
NMS Axis	Environmental Variable	Correlation [r]	N	*P*	BMI Metric	Correlation [r]	N	*P*	Taxon	Correlation [r]
Spring	Erosion	-0.7152	18	0.001	Oligochaeta %	-0.8337	21	0.000	Tubificidae	-0.8090
NMS	Total Phosphorus	-0.6887	13	0.009	Tolerance Value	-0.8331	21	0.000	Nematoda	-0.6330
Axis 1	K	-0.6523	14	0.012	Tolerant %	-0.7876	21	0.000	Crangonyx	0.5670
32.3%	Mud Habitat	-0.6213	20	0.004	Multivoltine %	-0.7025	21	0.000	Tanytarsini	0.5810
	Channelization	-0.6199	18	0.006	Collectors %	-0.4455	21	0.043	Hydropsyche	0.6980
	Turbidity	-0.5579	20	0.011	Chironomidae %	0.5090	21	0.018	Ephemerella	0.7500
	Clay	-0.5411	19	0.017	Odonata Taxa	0.5319	21	0.013	Baetis	0.7870
	Ag Land	-0.5403	20	0.014	Shannon Diversity	0.5351	21	0.012		
	Irrigation Return	-0.5365	21	0.012	Hydropsychidae %	0.6228	21	0.003		
	Silt	-0.4879	19	0.034	Filterers %	0.6523	21	0.001		
	Perennial	0.4567	21	0.037	Ephemeroptera %	0.6617	21	0.001		
	Boulder	0.4870	19	0.035	Sensitive EPT %	0.6943	21	0.001		
	Vegetated Banks	0.4935	21	0.023	Trichoptera Taxa	0.6958	21	0.001		
	Riffle	0.5030	20	0.024	Univoltine %	0.7035	21	0.000		
	Pasture	0.5571	20	0.011	ETO %	0.7169	21	0.000		
	Cobble	0.6338	19	0.004	Intolerant %	0.7179	21	0.000		
	Channel Sinuosity	0.6402	21	0.002	EPT %	0.7221	21	0.000		
	Elevation	0.6602	19	0.002	Baetidae %	0.7282	21	0.000		
	Epifaunal Substrate	0.6758	21	0.001	Trichoptera %	0.7343	21	0.000		
	Cobble Habitat	0.7260	20	0.000	Taxonomic Richness	0.7390	21	0.000		
	Pool Variability	0.7837	21	0.000	Ephemeroptera Taxa	0.7744	21	0.000		
	Width	0.7847	19	0.000	Insects %	0.7947	21	0.000		
					EPT Taxa	0.8075	21	0.000		
					ETO Taxa	0.8146	21	0.000		
					Sensitive EPT Taxa	0.8412	21	0.000		
					Intolerant Taxa	0.8686	21	0.000		
					Insect Taxa	0.8828	21	0.000		
Spring	High Water Mark	-0.6168	15	0.014	Odonata %	-0.6533	21	0.001	Coenagrionidae	-0.6700
NMS	Riparian Trees	-0.4745	19	0.040	Odonata Taxa	-0.5526	21	0.009	Hyalella	-0.6640
Axis 2	Rip. Zone Width	0.4481	21	0.042	Taxonomic Richness	-0.4747	21	0.030	Callibaetis	-0.6360
43.9%	Pasture	0.4695	20	0.037	Amphipods %	0.6211	21	0.003	Oxyethira	-0.5860
	Floating Algae	0.6154	18	0.007					Caenis	-0.5610
									Corophium	0.6930
Spring	Emergent Veg.	-0.5343	18	0.022	Predators %	-0.4762	21	0.029	Crangonyx	-0.5540
NMS	Urban Land	-0.4638	20	0.039	Filterers %	-0.4693	21	0.032	Tipulidae	0.5620
Axis 3	Sediment Odor	0.4652	21	0.034	Shredders %	0.4694	21	0.032	Naididae	0.5850
10.9%	Floating Algae	0.4980	18	0.035	Collectors %	0.5959	21	0.004		
	EC	0.5510	15	0.033						
	Cl	0.5599	13	0.047						
	Arsenic	0.6485	12	0.023						

Table 4. Environmental variables and benthic macroinvertebrate metrics significantly correlated with the axes of the NMS ordination performed on the fall 2002 BMI data (*P* < 0.05), along with taxa correlated with the axes (|r| > 0.400). Shading indicates negative correlations.

	Environmental Variables				**Metrics**				**Taxa**	
NMS Axis	Environmental Variable	Correlation [r]	N	*P*	BMI Metric	Correlation [r]	N	*P*	Taxon	Correlation [r]
Fall	Detritus	-0.6562	18	0.003	Collectors %	-0.7497	22	0.000	Tanypodinae	-0.6540
NMS	Sand Habitat	-0.5665	20	0.009	Chironomidae %	-0.6838	22	0.000	Caenis	-0.6280
Axis 1	Macrophyte Habitat	-0.5193	20	0.019	Amphipod Taxa	-0.5969	22	0.003	Hyalella	-0.5150
35.8%	Muck	-0.4997	18	0.035	Amphipods %	-0.4783	22	0.024	Planariidae	0.5040
	Channel Flow	0.4369	21	0.048	Tolerance Value	-0.4383	22	0.041	Simulium	0.5530
Fall	Pool Variability	-0.5929	21	0.005	Trichoptera Taxa	-0.7324	22	0.000	Baetis	-0.6520
NMS	Vegetated Banks	-0.5168	21	0.016	Sensitive EPT Taxa	-0.7053	22	0.000	Hydrobiidae	-0.5770
Axis 2	Attached Algae	-0.5041	18	0.033	EPT Taxa	-0.7039	22	0.000	Hydropsyche	-0.5570
36.7%	Elevation	-0.5024	19	0.028	Insect Taxa	-0.6899	22	0.000	Protoptila	-0.5150
	K	0.5488	14	0.042	ETO Taxa	-0.6896	22	0.000	Prostoma	0.5130
	Ammonia Nitrogen	0.6806	15	0.005	Intolerant Taxa	-0.6721	22	0.001	Planariidae	0.5350
	Kjeldhal Nitrogen	0.6968	9	0.037	EPT %	-0.6357	22	0.002	Polychaeta	0.6000
	Arsenic	0.7477	12	0.005	ETO %	-0.6165	22	0.002		
	Alkalinity	0.7885	8	0.020	Grazers %	-0.6025	22	0.003		
					Ephemeroptera Taxa	-0.5499	22	0.008		
					Baetidae %	-0.5418	22	0.009		
					Insects %	-0.5246	22	0.012		
					Trichoptera %	-0.4666	22	0.029		
					Coleoptera Taxa	-0.4655	22	0.029		
					Ephemeroptera %	-0.4588	22	0.032		
					Predators %	0.5784	22	0.005		
Fall	Cobble Habitat	-0.6573	20	0.002	Intolerant %	-0.6461	22	0.001	Oxyethira	-0.5110
NMS	Cobble	-0.6366	19	0.003	Univoltine %	-0.5922	22	0.004	Tubificidae	0.7540
Axis 3	Epifaunal Substrate	-0.5805	21	0.006	Intolerant Taxa	-0.5709	22	0.006		
11.6%	Riffle	-0.5763	20	0.008	Sensitive EPT %	-0.5236	22	0.012		
	Elevation	-0.5093	19	0.026	Sensitive EPT Taxa	-0.4738	22	0.026		
	Width	-0.5070	19	0.027	Shannon Diversity	-0.4587	22	0.032		
	Bank Stability	-0.5052	20	0.023	EPT Taxa	-0.4381	22	0.041		
	Gravel	-0.5025	19	0.028	Ephemeroptera Taxa	-0.4306	22	0.045		
	Pool Substrate	-0.4846	21	0.026	Tolerant %	0.5765	22	0.005		
	Boulder	-0.4625	19	0.046	Multivoltine %	0.5922	22	0.004		
	Sediment Deposition	-0.4369	21	0.048	Tolerance Value	0.6340	22	0.002		
	Mud Habitat	0.4898	20	0.028	Oligochaeta %	0.6888	22	0.000		
	Pool	0.5367	20	0.015						
	Irrigation Return	0.5451	21	0.011						
	Zn	0.6039	12	0.038						
	Total Organic Carbon	0.9552	5	0.011						

Table 5. Major taxonomic components of the BMI communities at sites on agricultural waterways in the San Joaquin River watershed sampled during spring and fall of 2002. %EPT: proportional abundance of EPT taxa; %IA: proportional abundance of non-EPT insect taxa plus amphipod taxa; %NIA: proportional abundance of non-insect, non-amphipod taxa. Sites along the same waterway are listed in order from upstream to downstream.

			Spring			Fall		
Site Category	Site		% EPT	% IA	%NIA	% EPT	% IA	%NIA
Rivers	Merced River @ Hwy 59	MER581	74	16	10	57	12	31
	Merced River @ J16 Oakdale Rd.	MER580	59	31	10	54	27	19
	Merced River @ Hatfield Park (River Rd)	MER546	22	63	16	14	51	36
	Cosumnes R. @ Michigan Bar Rd.	SAC003	33	63	4	9	52	39
	Cosumnes River @ Hwy 16	SAC004	23	68	9	2	52	46
	Mokelumne R. @ Van Assen Co. Park	SJC512	19	53	28	32	29	39
	Calaveras River @ Shelton Rd.	SJC514	22	44	34	33	9	57
Southern Aqricultural Streams	Mud Slough Up Stream of SLD	MER536	1	73	26	2	76	22
	Mud Slough Down Stream of SLD	MER542	0	69	31	0	60	39
	Salt Slough @ Lander/Hwy 165	MER531	7	91	3	2	30	69
	Bear Creek @ Bert Crane Rd.	MER007	4	16	79	2	15	83
	Los Banos Creek @ Hwy 140	MER554	0	23	77	1	32	68
	Ingalsby Slough @ J17 Turlock	MER579	6	37	57	2	45	53
	Harding Drain @ Carpenter Rd.	STC501	-	-	-	5	4	91
West Side Aqricultural Streams	Orestimba Creek @ Bell Rd.	STC517	69	20	11	71	29	0
	Orestimba Creek @ River Rd.	STC019	2	17	81	1	21	77
	Del Puerto Creek @ Vineyard	STC516	0	37	63	0	9	91
	Ingram Creek @ River Rd.	STC040	0	14	86	0	4	96
Northern Aqricultural Streams	Lone Tree Creek @ Austin Rd.	SJC503	1	64	35	3	5	92
	French Camp Slough @ Airport Rd.	SJC504	3	25	73	66	12	22
	Bear Creek @ Lower Sacramento Rd.	SJC515	0	41	59	0	19	81
	Mtn. House Creek @ Byron Rd.	SJC509	0	6	94	4	39	57

Table 6. Benthic macroinvertebrate community metrics of samples collected at Lone Tree Creek (SJC503) on 16 October 2002, where two multihabitat samples and one CSBP sample were taken simultaneously.

	Multihabitat	Multihabitat Duplicate	CSBP Random 500 Bugs	CSBP Cumulative 900 Bugs	CSBP Transect 1	CSBP Transect 2	CSBP Transect 3
Taxonomic Richness	11	9	19	19	8	14	16
Insect Taxa	6	6	9	9	4	8	7
EPT Taxa	3	1	4	4	1	3	2
ETO Taxa	3	1	4	4	1	3	2
Ephemeroptera Taxa	1	1	2	2	0	2	1
Plecoptera Taxa	0	0	0	0	0	0	0
Trichoptera Taxa	2	0	2	2	1	1	1
Coleoptera Taxa	0	0	0	0	0	0	0
Odonata Taxa	0	0	0	0	0	0	0
Amphipod Taxa	0	0	1	1	0	1	1
Sens EPT Taxa	0	0	0	0	0	0	0
Intolerant Taxa	0	0	0	0	0	0	0
EPT Index	3.0	2.7	5.2	4.4	0.3	3.5	9.5
ETO Index	3.0	2.7	5.2	4.4	0.3	3.5	9.5
Sensitive EPT Index (<4)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shannon Diversity	0.84	0.86	1.97	1.93	1.43	1.73	2.18
Tolerance Value	8.7	9.3	7.9	7.9	8.5	8.1	7.3
Percent Intolerant Organisms	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percent Tolerant Organisms	90.0	88.8	72.6	73.9	80.5	79.4	61.8
Percent Amphipods	0.0	0.0	0.8	0.6	0.0	0.3	1.4
Percent Insects	8.3	11.2	19.0	17.1	9.8	14.7	27.0
Percent Trichoptera	0.8	0.0	1.0	1.3	0.3	0.3	3.2
Percent Hydropsychidae	0.6	0.0	0.8	1.2	0.3	0.0	3.2
Percent Ephemeroptera	2.2	2.7	4.2	3.1	0.0	3.1	6.3
Percent Baetidae	2.2	2.7	4.0	3.0	0.0	2.8	6.3
Percent Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percent Ceratopogonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percent Chironomidae	4.1	8.0	12.4	11.7	9.4	10.5	15.1
Percent Odonata	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percent Oligochaeta	10.2	78.4	45.2	44.8	39.4	50.7	44.2
Percent Dominant Taxon	79.3	78.0	27.2	29.0	41.1	28.7	30.9
% Univoltine/Longer	0.2	0.0	0.4	0.2	0.0	0.7	0.0
% Bivoltine or More	99.8	100.0	99.6	99.8	100.0	99.3	100.0
Percent Collectors	16.9	86.3	60.2	58.3	47.0	63.3	64.6
Percent Filterers	79.9	12.0	30.4	32.2	43.2	29.4	23.9
Percent Grazers	1.8	0.0	1.2	1.3	0.0	0.7	3.2
Percent Predators	0.2	1.0	6.8	7.2	9.8	5.9	6.0
Percent Shredders	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. Benthic macroinvertebrate community metrics of samples collected at French Camp Slough (SJC504) on 16 October 2002, where one multihabitat sample and one CSBP sample were taken simultaneously.

	Multihabitat	CSBP Random 500 Bugs	CSBP Cumulative 900 Bugs	CSBP Transect 1	CSBP Transect 2	CSBP Transect 3
Taxonomic Richness	12	17	17	12	12	9
Insect Taxa	8	9	9	6	7	5
EPT Taxa	2	3	3	3	2	2
ETO Taxa	3	4	4	3	3	2
Ephemeroptera Taxa	1	2	2	2	1	1
Plecoptera Taxa	0	0	0	0	0	0
Trichoptera Taxa	1	1	1	1	1	1
Coleoptera Taxa	0	0	0	0	0	0
Odonata Taxa	1	1	1	0	1	0
Amphipod Taxa	1	1	1	1	0	1
Sens EPT Taxa	0	0	0	0	0	0
Intolerant Taxa	0	0	0	0	0	0
EPT Index	66.0	42.0	40.5	78.9	36.8	5.7
ETO Index	66.4	42.2	40.7	78.9	37.2	5.7
Sensitive EPT Index (<4)	0.0	0.0	0.0	0.0	0.0	0.0
Shannon Diversity	1.27	1.64	1.69	1.03	1.88	0.80
Tolerance Value	5.3	6.7	6.7	4.5	6.3	9.3
Percent Intolerant Organisms	0.0	0.0	0.0	0.0	0.0	0.0
Percent Tolerant Organisms	19.3	43.6	43.1	4.7	36.5	88.2
Percent Amphipods	0.4	0.4	0.6	0.3	0.0	1.3
Percent Insects	77.4	48.4	48.5	88.3	48.3	8.8
Percent Trichoptera	63.7	41.0	39.0	75.8	35.4	5.4
Percent Hydropsychidae	63.7	41.0	39.0	75.8	35.4	5.4
Percent Ephemeroptera	2.3	1.0	1.6	3.0	1.4	0.3
Percent Baetidae	2.3	0.8	1.2	2.3	1.4	0.0
Percent Coleoptera	0.0	0.0	0.0	0.0	0.0	0.0
Percent Ceratopogonidae	0.0	0.0	0.0	0.0	0.0	0.0
Percent Chironomidae	8.3	5.8	7.5	9.1	10.4	3.0
Percent Odonata	0.4	0.2	0.1	0.0	0.3	0.0
Percent Oligochaeta	16.4	33.4	34.0	4.0	16.7	80.8
Percent Dominant Taxon	63.7	41.0	39.0	75.8	35.4	80.8
% Univoltine/Longer	0.0	0.0	0.0	0.0	0.0	0.0
% Bivoltine or More	100.0	100.0	100.0	100.0	100.0	100.0
Percent Collectors	26.6	40.2	42.9	16.1	27.8	84.5
Percent Filterers	66.4	50.0	47.0	76.8	50.7	13.5
Percent Grazers	3.3	7.4	7.2	4.7	15.6	1.7
Percent Predators	1.0	2.0	2.5	2.0	5.2	0.3
Percent Shredders	0.0	0.0	0.0	0.0	0.0	0.0

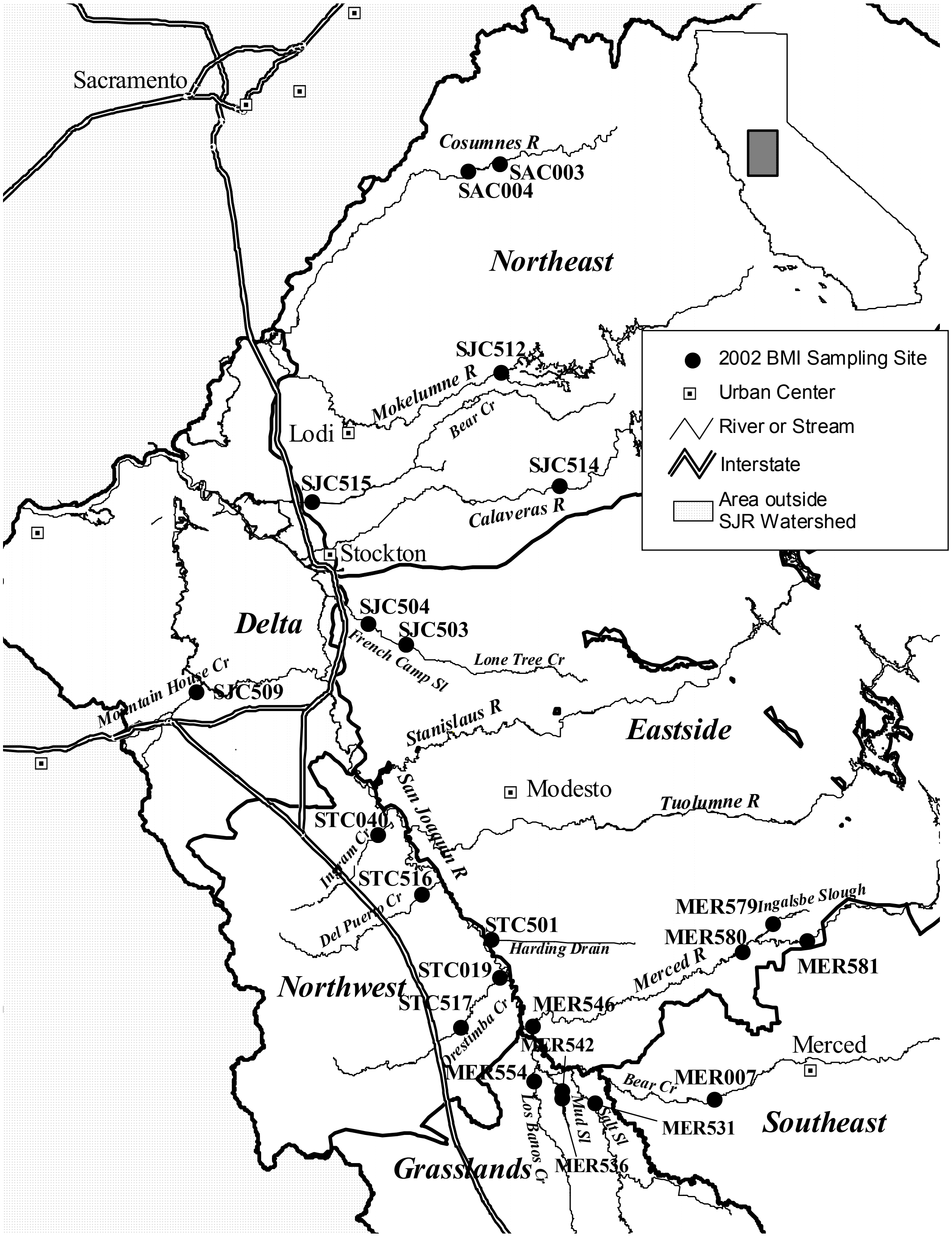

Figure 1a. Site locations for BMI community sampling in spring and fall 2002 and sub-watersheds of the San Joaquin River watershed.

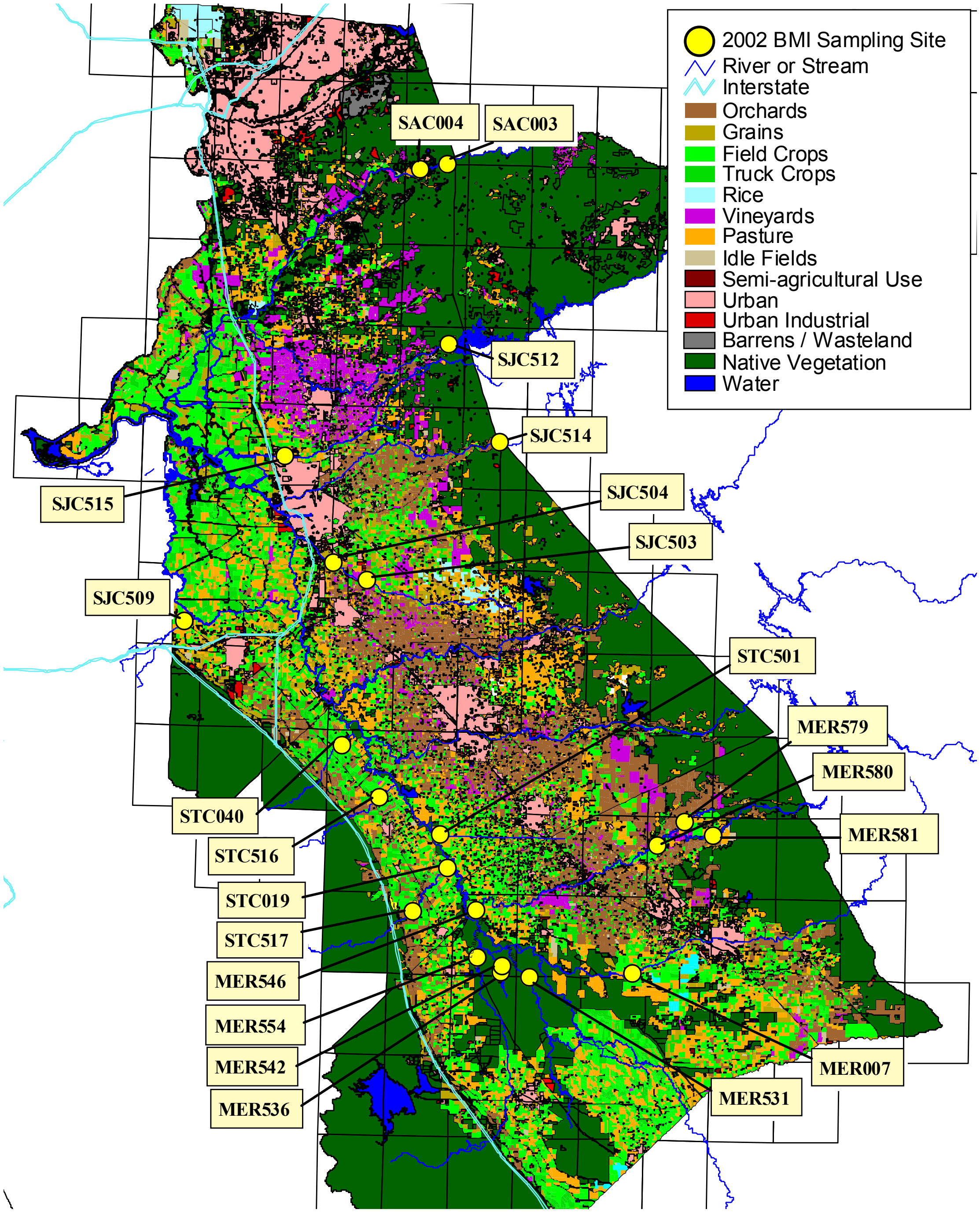

Figure 1b. Site locations for BMI community sampling in spring and fall 2002 and sub-watersheds of the San Joaquin River watershed.

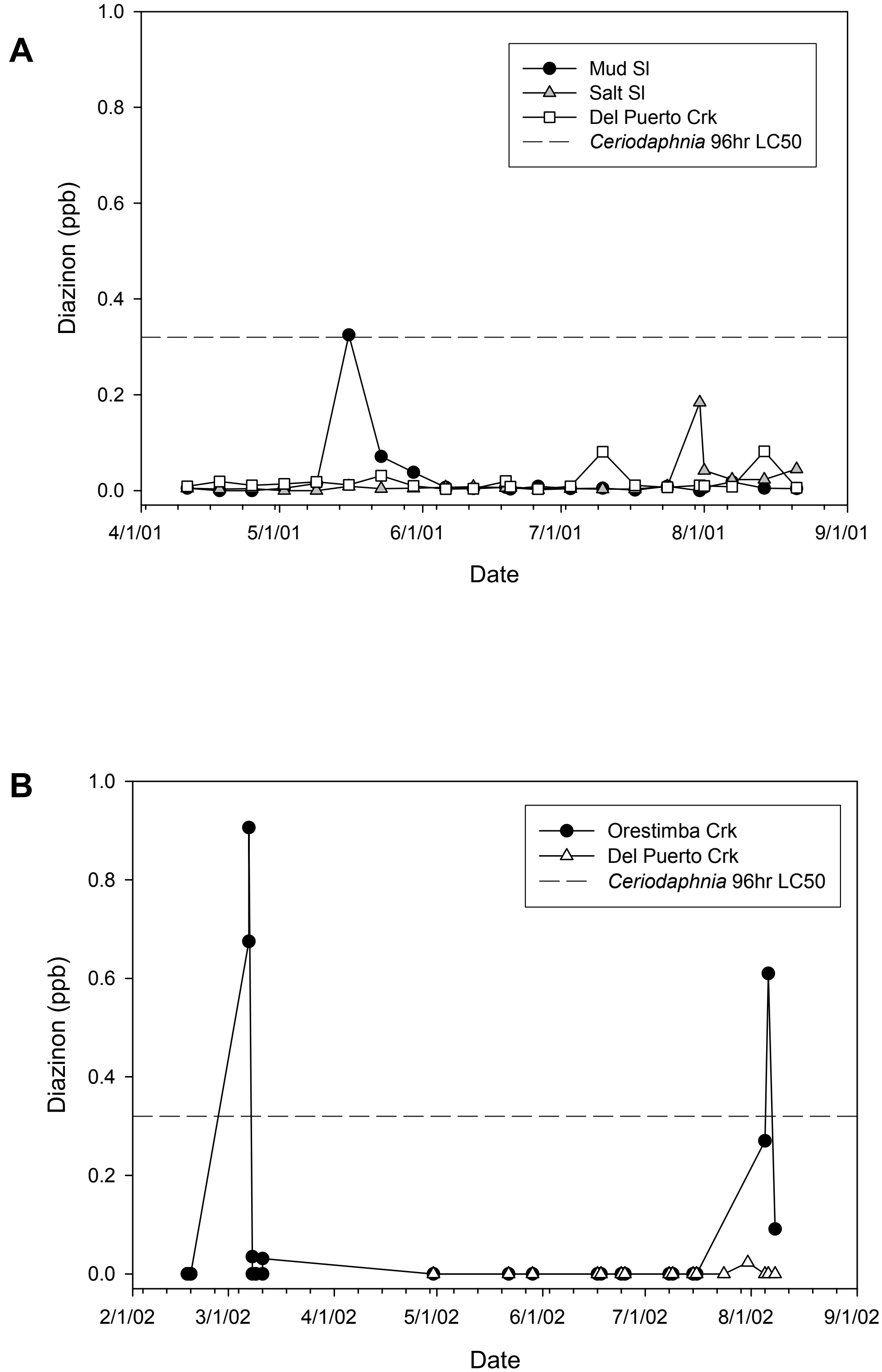

Figure 2. Water column diazinon concentrations before and during the seasons of benthic macroinvertebrate community sampling. A: 2001 data; B: 2002 data.

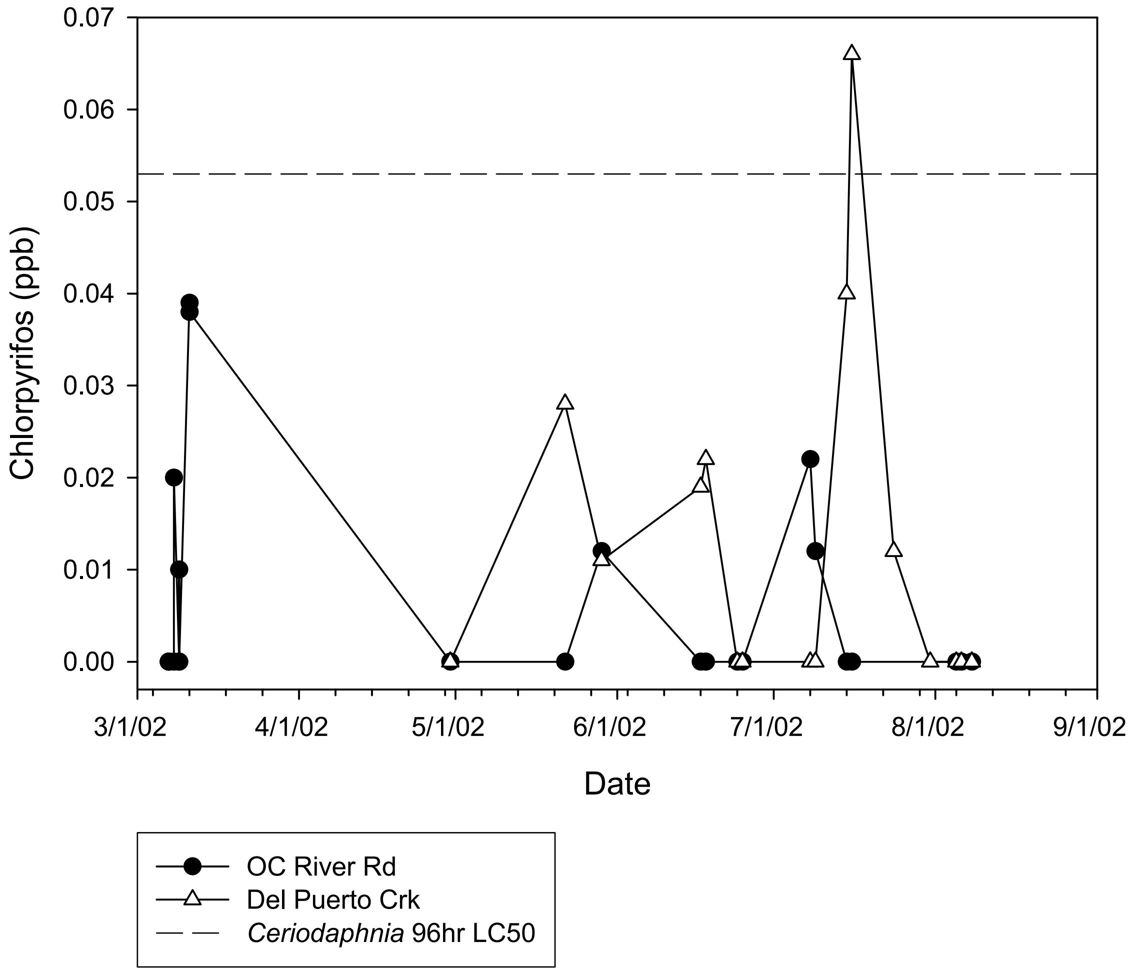

Figure 3. Water column chlorpyrifos concentrations before and during the seasons of benthic macroinvertebrate community sampling.

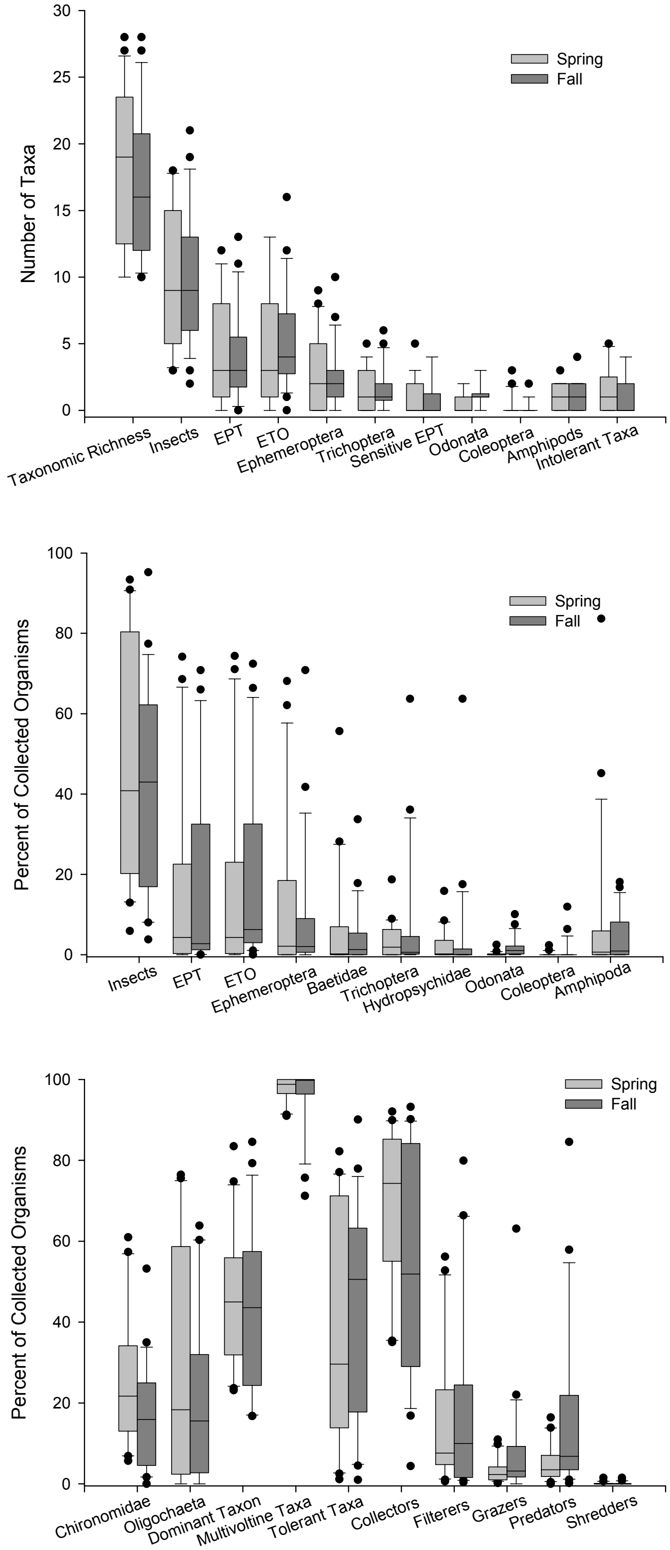

Figure 4. Distributions of benthic macroinvertebrate community metrics during the spring and fall 2002 sampling events. Horizontal lines on bars are medians, bars 75th and 25th percentiles, vertical lines 90th and 10th percentiles and dots outliers.

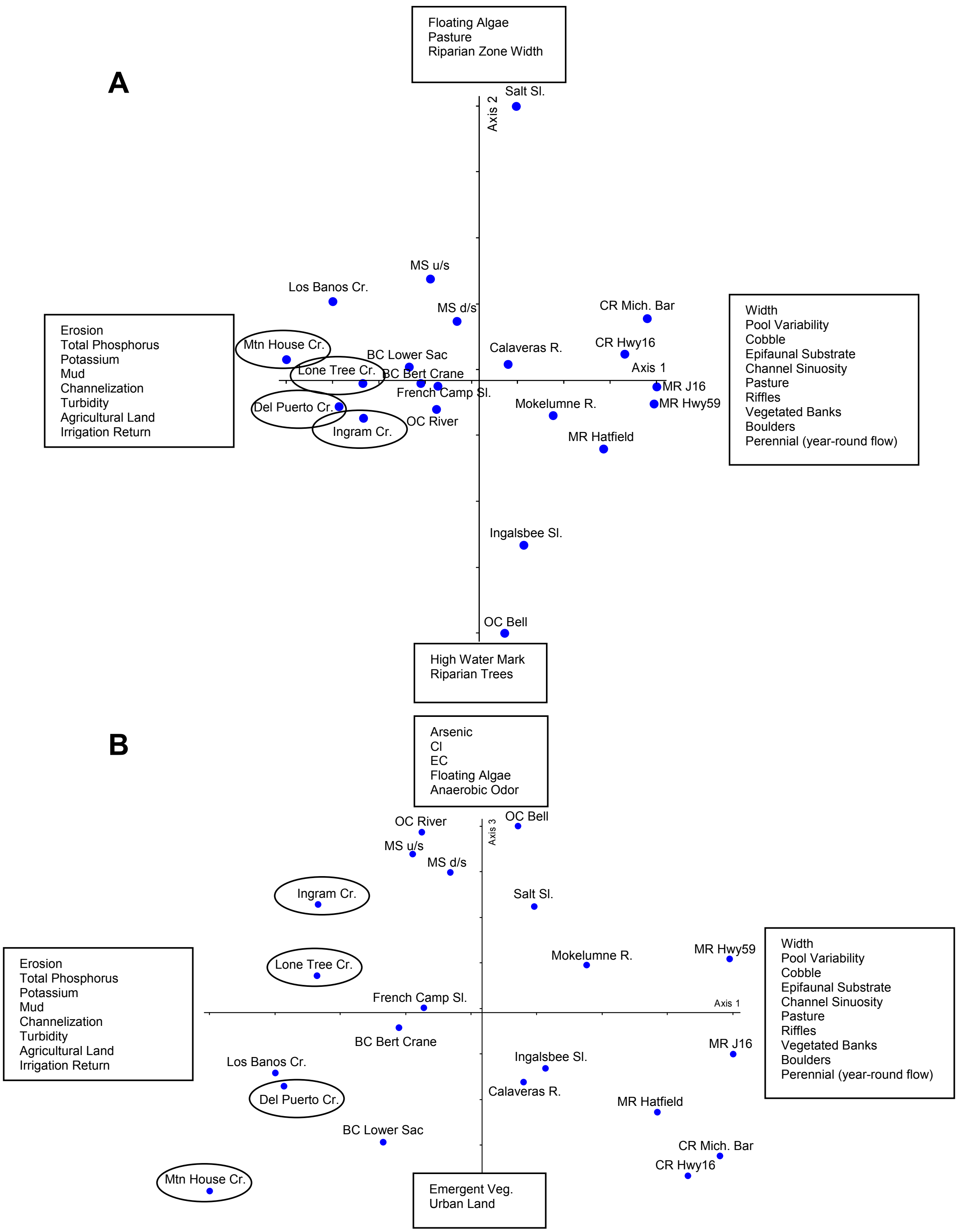

Figure 5. Nonmetric Multidimensional Scaling (NMS) ordination of benthic macroinvertebrate samples at sites in the San Joaquin River watershed sampled 5/13/2002 – 5/23/2002. Boxes at the ends of each axis show environmental variables significant correlated with the axes ($P < 0.05$). Circled sites showed a near total absence of insects. A: Axes 1 and 2. B: Axes 1 and 3.

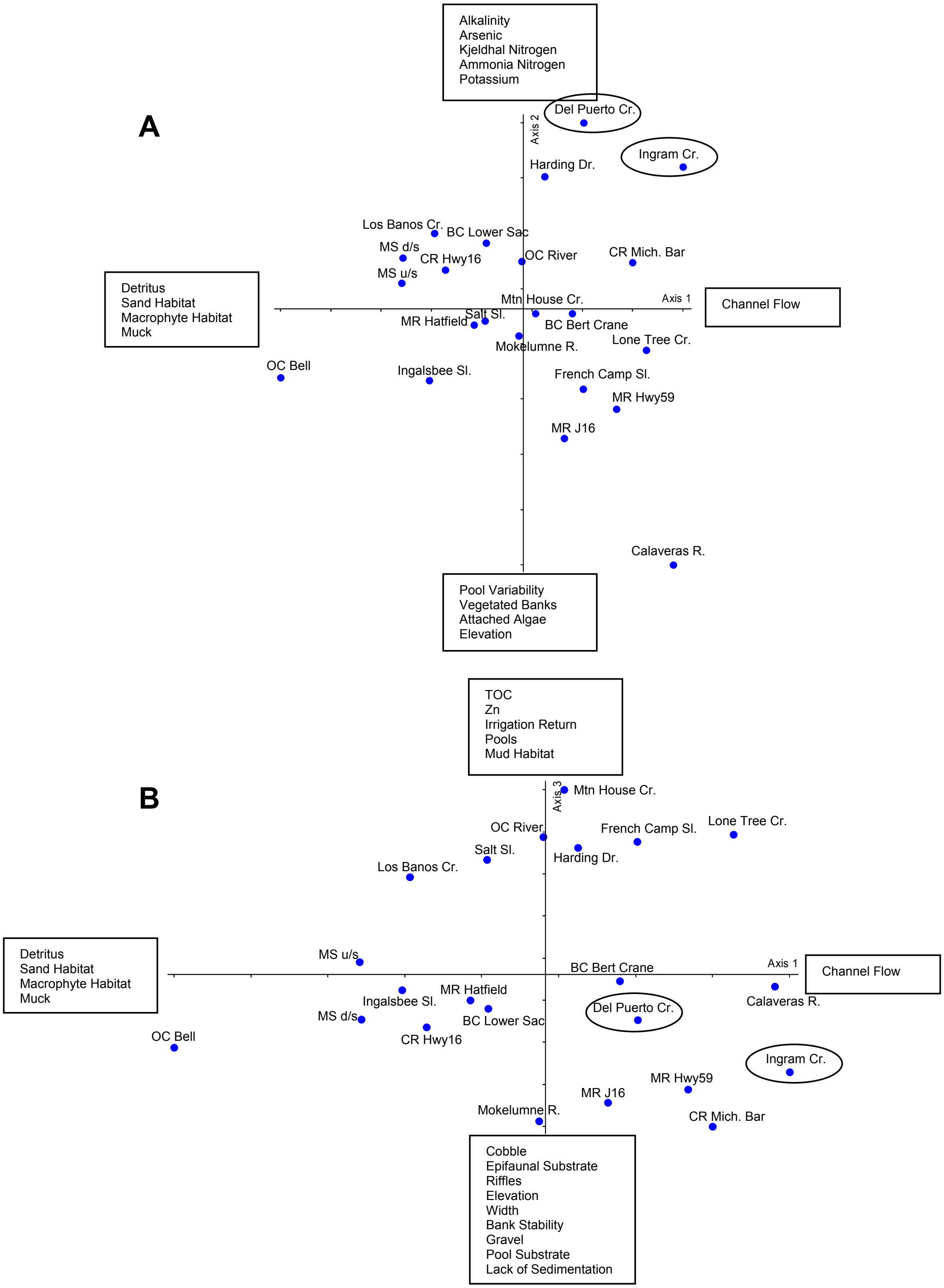

Figure 6. Nonmetric Multidimensional Scaling (NMS) ordination of benthic macroinvertebrate samples at sites in the San Joaquin River watershed sampled 9/30/2002 – 10/23/2002. Boxes at the ends of each axis show environmental variables significant correlated with the axes ($P < 0.05$). Circled sites showed a near total absence of insects. A: Axes 1 and 2. B: Axes 1 and 3.

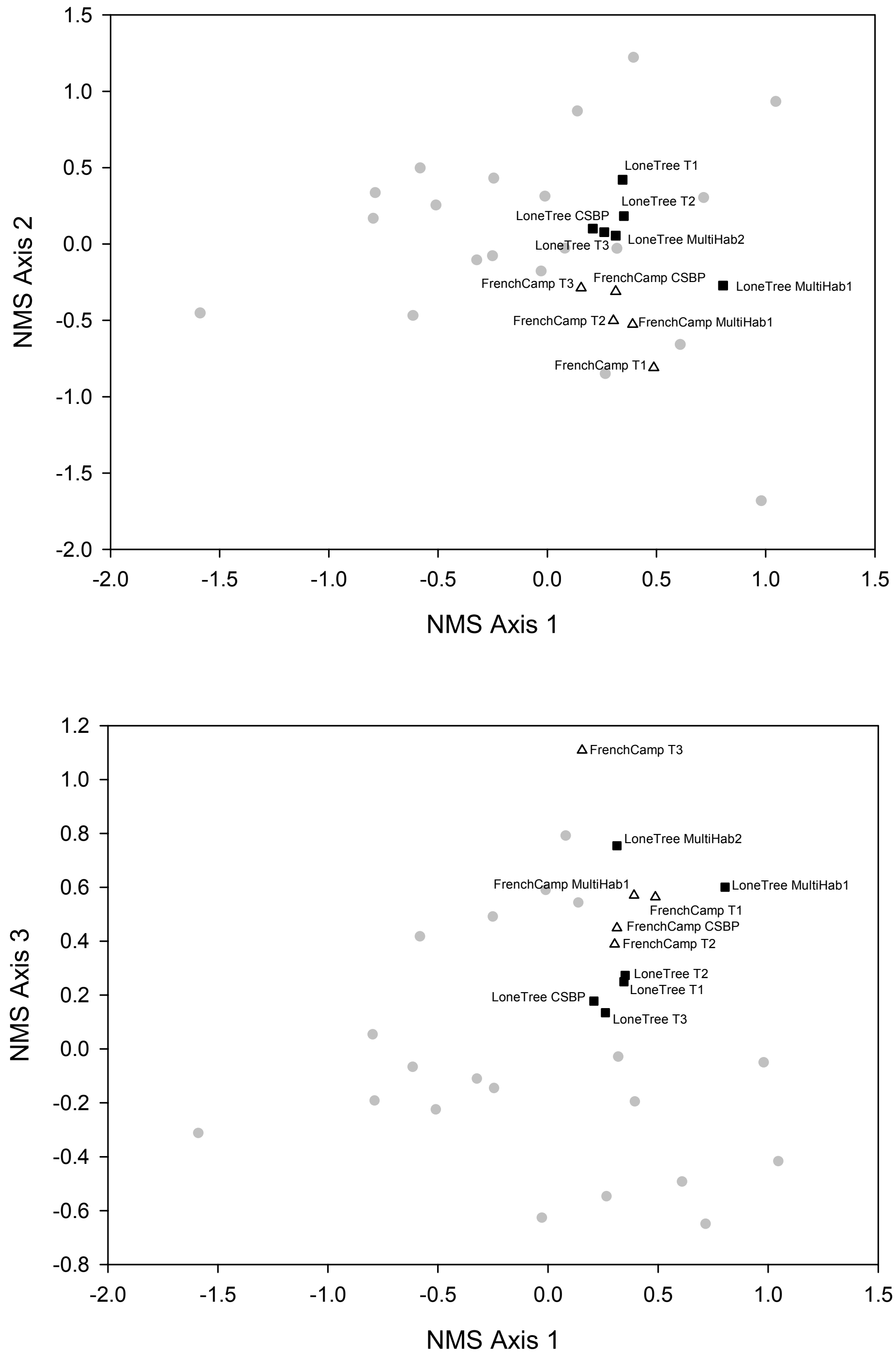

Figure 7. Predicted NMS scores of benthic macroinvertebrate samples collected simultaneously by CSBP, CSBP transect (T1, T2, T3), and multi-habitat protocols during the fall 2002 sampling event. These plots illustrate the variability of the multi-habitat method and provide a comparison of CSBP and multi-habitat results. Grey points depict site NMS scores of sites where no duplicate or CSBP samples were collected.